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Vol. 6. Part 1 May, 1923 Number 32

BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

PROCEEDINGS

OF THE

SECOND ANNUAL MEETING

OF THE

ADVISORY BOARD ON HIGHWAY RESEARCH, DIVISION OF ENGINEERING, NATIONAL RESEARCH COUNCIL

EDITED BY

WILLIAM KENDRICK HATT, *Director, Advisory Board*

Held at Washington, D. C.

November 23, 1922

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
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Vol. 6. Part 1 May, 1923 Number 32

BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

PROCEEDINGS OF THE SECOND ANNUAL MEETING OF THE ADVISORY BOARD ON HIGHWAY RESEARCH, DIVISION OF ENGINEERING, NATIONAL RESEARCH COUNCIL

Edited by William Kendrick Hatt, *Director, Advisory Board*

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PART I

SUMMARY OF DEVELOPMENT OF ADVISORY BOARD

CHRONOLOGICAL STATEMENT

The National Research Council was established in the spring of 1916 when President Wilson requested the National Academy of Sciences to organize the scientific and engineering forces of the United States for the purpose of defense. The Engineering Committee of the National Research Council did effective work during the war.

On May 18, 1918, by executive order, President Wilson perpetuated the National Research Council and attached it to the National Academy of Sciences which was incorporated by congressional charter, approved by President Lincoln, March 3, 1863.

The Division of Engineering of the National Research Council occupies offices in the Engineering Societies' Building, New York. The Engineering Foundation, which is closely affiliated with the Engineering Division, provides an office for the Division adjoining its own, and contributes a portion of the funds needed for the administrative expenses of the Division.

Advisory Board on Highway Research.

On October 8, 1919, Professor A. N. Talbot and Dean Anson Marston, representatives of organizations in the Division of Engineering, met in Chicago in conjunction with the following:

For the Bureau of Public Roads:
T. H. MacDonald, Chief.
A. T. Goldbeck, in charge of Tests and Investigations.
T. W. Allen, Chief, Division of Control.
J. T. Voshell, District Engineer.

For the Mississippi Valley State Highway Department Association:
Clifford Older, President.

After discussing the importance and necessity for the immediate inauguration of a national program for highway research, and listing the highway research agencies, it was recommended (in a report dated October 27, 1919, and signed by Messrs. A. N. Talbot, Anson Marston, H. H. Porter and George S. Webster), that a sub-committee of the Engineering Division be appointed to cooperate with the Chairman in coordinating the various highway research committees, and that six committees be constituted as follows:

(1) Committee on the Economic Theory of Highway Improvement.

Purpose: Determination of all elements of cost of highway transportation (both motor vehicle and animal drawn), and the effect upon each cost element of each feature of highway improvement (improved surface, grade reduction, elimination of rise and fall, etc.) to enable reliable and scientific determination of the sums which could be economically expended for scientific highway improvement.

(2) Committee on Structural Design of Roads.

Purpose: Experimental determination of stresses, strains and behavior, of impact and abrasion in actual roadways under actual traffic; including also the effect of temperature variations, freezing and thawing, non-uniform sub-grades and other factors; in order to establish reliable scientific engineering theory for the structural design of roads.

(3) Committee on Properties of Road Materials.

Purpose: To investigate the properties of road materials and their combinations, including devising and standardizing tests.

(4) Committee on Methods of Road Construction.

(5) Committee on Maintenance Methods and Design.

(6) Committee on Highway Bridge and Culvert Research.

On October 26, 1920, the Chairman of the Engineering Division addressed a communication to the governing boards of certain national organizations, Federal and State departments, and educational institutions, stating the need for highway research, outlining projected committee organization, and inviting representatives to a conference for the purpose of completing the organization.

At that meeting, held November 11, 1920, an Advisory Board on Highway Research was organized and by-laws adopted. The offices created were—Chairman, Vice-Chairman and Director; the administrative committees created were—Executive, and Ways and Means; the research committees created were—on Bibliography, on Economic Theory of Highway Improvement, on Structural Design of Roads, and on Character and Use of Road Materials.

The by-laws, finally adopted, follow:

BY-LAWS

As adopted November 11, 1920, and amended January 16, 1922

1. *Name:* Advisory Board on Highway Research of National Research Council.

2. *Purposes:*
   - (a) To assist in outlining a comprehensive national program of highway research and coordinating activities thereunder.
   - (b) To organize committees for specific problems.
   - (c) To deal with ways and means.
   - (d) To act in a general advisory capacity.

3. *Membership:* Those organizations of national importance interested in design, construction, economics, maintenance and financing of highways, in materials and equipment therefor, and in vehicles used on highways; governmental departments and bureaus of similar interests, and the higher educational institutions, each acting through one duly appointed representative, with authority to name an alternate, serving until appointment of his successor. New organization members shall be elected by letter ballot of the Board upon recommendation by Executive Committee. Qualification shall be completed within three months by appointment of a representative.

4. *Officers:* Chairman, Vice-Chairman and Director, who shall perform the usual functions. Chairman and Vice-Chairman elected annually by the Board in meeting or by letter ballot; to serve one year from January 1 following election, or until successors qualify. In case of letter ballot, nominations shall be made by Executive Committee or by Division of Engineering.

5. *Director:* Shall be engaged by Executive Committee and serve at the will of this committee; shall be paid a salary fixed by that committee; shall be the executive officer of the Board; shall be a professional engineer; shall devote his whole time to the duties of his office; shall account to the Executive Committee for all monies received and disbursed.

6. *Administrative Committees:*
   - (a) *Executive:* Consisting of the Chairman, the Vice-Chairman and three additional members chosen by the Board, at least two of whom shall also be members of the Division of Engineering.
   - (b) *Ways and Means:* Three members appointed by the Chairman.

   Duties: Those indicated by the titles and such others as may be assigned by the Board. Executive Committee shall also aid Chairman and Director in carrying out instructions of the Board and in formulating projects to be presented to the Board; shall act for the Board in routine matters, and shall control publicity.

7. *Research Committees:* Shall be created by the Board, as deemed necessary, with the approval of the Division of Engineering. Members shall be appointed by the Chairman of the Board with approval of the Executive Committee, and need not be limited to members of the Board. The following are established upon adoption of these By-Laws:
   (a) Bibliography.[1]
   1. Economic Theory of Highway Improvement.
   2. Structural Design of Roads.
   3. Character and Use of Road Materials.
   4. Highway Traffic Analysis.
   5. Highway Bridges.[1]
   6. Highway Finance.
   7. Maintenance of Highways.

8. *Meetings:* Annual meeting, second Thursday of November, at a place to be designated by the Chairman.
   Other meetings at call of Executive Committee, on twenty days' notice.

9. *Amendments:* May be made by a majority of the Board, on thirty days' notice, by letter ballot.

The purposes of the Board are briefly: To prepare a comprehensive national program for highway research; to assist existing organizations in coordinating their activities and to collect and distribute information of completed and current research.

On July 11, 1921, the Executive Committee met and engaged a Director and authorized the Chairman and Vice-Chairman to prepare cooperative agreements with the Bureau of Public Roads, the State Highway Departments, and other organizations adapted to instituting and coordinating a national program for highway research. It was voted that the National Research Council be requested to act as financial agent for the Advisory Board, and that the Vice-Chairman of the Board be authorized to approve bills and sign requisitions for payment of expenses.

The following resolutions on committees were adopted:

Voted,—that no person be appointed to a research committee under the auspices of the Advisory Board on Highway Research who cannot devote sufficient time to the committee's work, and that the personnel of each committee be subject to approval by the Executive Committee.

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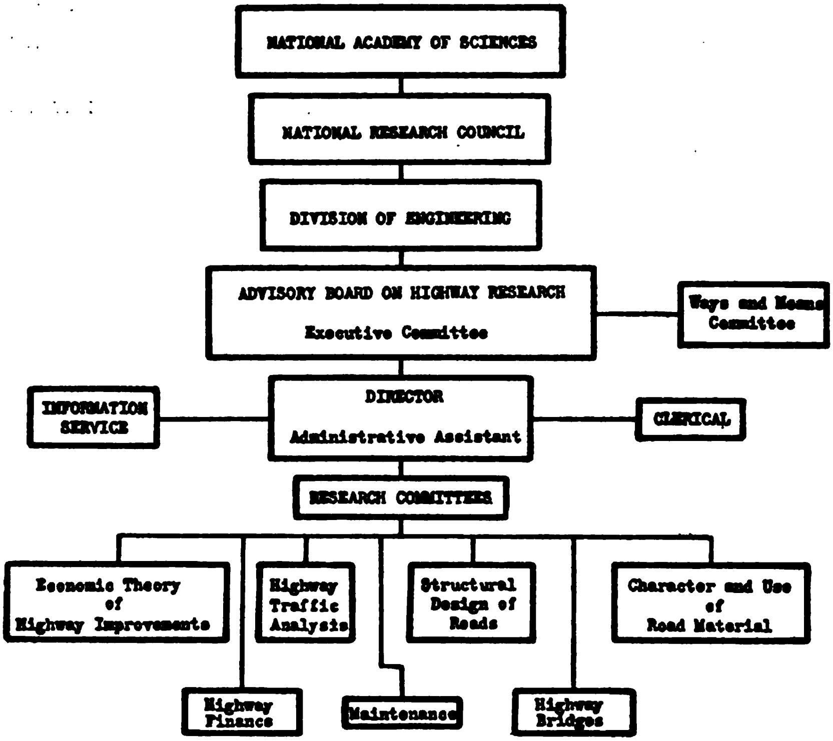
[1] Committee not yet organized.

It is the consensus of opinion that whenever desirable, the personnel of a committee shall include suitable representatives of interested industries.

On December 2, 1921, a report of this conference was sent to all participating individuals and organizations.

ADVISORY BOARD ON HIGHWAY RESEARCH: CONSTITUENT MEMBERS AND REPRESENTATIVES



Officers and Members of Executive Committee for 1923

Chairman: A. N. Johnson, Dean, College of Engineering, University of Maryland.

Vice-Chairman: Alfred D. Flinn, Member, Am. Soc. Civil Engineers; Director, Engineering Foundation; formerly Deputy Chief Engineer, Catskill Water Supply for New York City.

Other Members of Executive Committee:

Henry M. Crane, Chairman of Research Committee, Society of Automotive Engineers.

Thomas H. MacDonald, Chief of Bureau of Public Roads, U. S. Department of Agriculture.

T. R. Agg, Division of Engineering, N. R. C., Iowa State College.

Director: William K. Hatt, Professor of Civil Engineering and Director of Materials Testing Laboratory, Purdue University, Lafayette, Indiana.

MEMBER ORGANISATIONS AND THEIR REPRESENTATIVES

American Association of State Highway Officials:
  Representative, W. D. Uhler (Deceased Oct. 27, 1922.)*
American Concrete Institute:
  Representative, W. M. Kinney
  Alternate, E. J. Moore
American Institute of Consulting Engineers:
  Representative, S. Whiney
  Alternate, F. A. Molitor
American Society of Civil Engineers:
  Representative, Robert A. Cummings
  Alternate, J. S. Langthorn
American Society of Mechanical Engineers:
  Representative, H. de B. Parsons
  Alternate, Daniel E. Moran
American Society for Municipal Improvements:
  Representative, Nelson P. Lewis
  Alternate, Manley Osgood
American Society for Testing Materials:
  Representative, Prevost Hubbard
  Alternate, A. N. Johnson
Associated General Contractors of America:
  Representative, H. H. Wilson
  Alternate, George M. Eady
Association of American State Geologists:
  Representative, W. O. Hotchkiss
  Alternate, E. B. Mathews
Bureau of Public Roads, U. S. Department of Agriculture:
  Representative, Thos. H. MacDonald
  Alternate, A. T. Goldbeck
Bureau of Standards, U. S. Department of Commerce:
  Representative, W. A. Slater
  Alternate, H. L. Whittemore
Corps of Engineers, U. S. Army:
  Representative, Col. John C. Oakes
Eno Foundation for Highway Traffic Regulation:
  Representative, William P. Eno
Engineering Foundation:
  Representative, Alfred D. Flinn

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* Between the time of meeting and time of going to press, Clifford Older has been appointed.

National Automobile Chamber of Commerce:
  Representative, A. J. Brosseau
National Highway Traffic Association:
  Representative, Arthur H. Blanchard
  Alternate, George H. Pride
Rubber Association of America:
  Representative, H. S. Firestone
  Alternate, A. L. Viles
Society of Automotive Engineers:
  Representative, David Beecroft
  Second Representative, H. W. Alden
  Alternate, Henry M. Crane
Western Society of Engineers:
  Representative, A. N. Talbot
  Alternate, Linn White
American Road Builders' Association:
  Representative, H. E. Breed
  Alternate, H. G. Shirley
National Safety Council:
  Representative, R. I. Kelker, Jr.
  Alternate, Fred M. Rosseland
Association of Land Grant Colleges:
  Representative, Anson Marston.

RESEARCH COMMITTEES

(1) COMMITTEE ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT.

Problem: To determine all of the elements of cost of highway improvement.

The following will suggest the type of research involved:

A. Effect of grades, alignment, rise and fall, weather and speed and methods of operation on cost of transport.

B. Determination of all of the elements entering into the resistance to translation of vehicles (tractive resistance) and magnitude of each element.

C. Determination of the elements of cost of vehicle transportation classed as capital costs, and operating costs exclusive of those included in A and B.

D. To determine the relation between traffic and capital and maintenance costs of roads.

Membership:

Chairman, T. R. Agg, Iowa State College
L. E. Conrad, Kansas State Agricultural College
H. C. Dickinson, Society of Automotive Engineers
H. S. Fairbank, U. S. Bureau of Public Roads
A. B. Fletcher, Boston, Mass.
H. J. Hughes, Harvard University
Mark L. Ireland, Quartermaster Corps, U. S. Army
E. W. James, U. S. Bureau Public Roads
H. J. Kuelling, Wisconsin State Highway Commission
E. H. Lockwood, Yale University
Charles M. Manly, New York City
Tom Snyder, Indianapolis, Ind.

(2) COMMITTEE ON STRUCTURAL DESIGN OF ROADS.

Problem: To establish all of the data required for the rational design of a road surface.

The following will suggest the type of research involved:

A. To determine all facts relative to the behavior of the soil upon which roads are constructed, when under load from the road structure.

B. To determine the relation between traffic loads and stress in road surfaces, and to establish the laws that control.

C. To determine the effects of the elements on road structures.

D. To determine the structural strength of all types of road surfaces.

E. Relation of the vehicle to the road.

Membership:

Chairman, A. T. Goldbeck, U. S. Bureau of Public Roads
C. A. Hogentogler, U. S. Bureau of Public Roads, Secretary
Lloyd Aldrich, San Francisco, California
H. C. Berry, University of Pennsylvania
H. E. Breed, New York University
F. H. Eno, Ohio State University
E. W. James, U. S. Bureau of Public Roads

Clifford Older, Division of Highways, State of Illinois
H. G. Shirley, Virginia State Highway Commission
E. B. Smith, U. S. Bureau of Public Roads
C. M. Strahan, University of Georgia
E. W. Templin, Akron, Ohio
C. M. Upham, North Carolina State Highway Commission
H. M. Westergaard, University of Illinois

(3) COMMITTEE ON CHARACTER AND USE OF ROAD MATERIALS.

Problem: To determine the most effective combinations of materials to give desired strength, and to investigate possible new combinations of materials.

The following will suggest the type of research involved:

A. To establish the most effective combinations of materials now in use, with particular reference to the exigencies of the field control.
B. To promote research looking to the establishment of new combinations of materials, or of the new materials suitable for road surfacing.

Membership:

Chairman, H. S. Mattimore, Pennsylvania State Highway Department
B. A. Anderton, U. S. Bureau of Public Roads
E. W. Crum, Iowa State Highway Commission
F. C. Lang, University of Minnesota
C. S. Reeve, New York City
H. H. Scofield, Cornell University
M. O. Withey, University of Wisconsin

(4) COMMITTEE ON HIGHWAY TRAFFIC ANALYSIS.

Problem: To establish an adequate method of studying highway traffic and to show how traffic records should be interpreted.

The following will suggest the type of research involved:

A. To study relation of community development of the origin and destination of traffic, and to devise means for estimating potential traffic.

B. Proper method for studying and recording volume of traffic, and for interpreting traffic records.

C. To devise units of measure to apply to traffic and to define those units.

D. To study the relation of highway betterment to traffic increases.

Membership:

Chairman, Geo. E. Hamlin, Connecticut State Highway Commission
T. R. Agg, Iowa State College
A. H. Blanchard, University of Michigan
N. W. Dougherty, University of Tennessee
A. N. Johnson, University of Maryland
Nelson P. Lewis, New York City
J. H. Mullen, Minnesota State Highway Department

(5) COMMITTEE ON HIGHWAY BRIDGES.

Problem: To establish all of the data required for the design of highway bridges.

The following will indicate the type of research required:

A. Determination of loads for which bridges should be designed.

B. Study of impact on highway bridges.

C. Determination of the proper requirements for standards of design as regards allowable stresses, width and requirements of foundations.

(Committee not yet organized)

(6) COMMITTEE ON HIGHWAY FINANCE.

Problem: To determine the equitable basis for financing highway improvements.

The following will indicate the type of research involved:

A. Definition of an equitable basis for highway financing.

B. Study of possible methods of financing improvements in the various political units.

C. Administrative methods required to insure equitable financing.

Membership:

Chairman, J. G. McKay, U. S. Bureau of Public Roads
(Committee not yet organized)

(7) COMMITTEE ON MAINTENANCE.

Problem: To determine the relation between traffic and maintenance costs of roads, to investigate methods of maintenance and organization of maintenance forces.

The following will suggest the type of research involved:

A. Establishment of accounting methods that will give accurate data on cost of maintenance.

B. Methods of correlating maintenance costs and volume of traffic.

C. Relation of maintenance costs to methods of maintenance.

Membership:

Chairman, W. H. Root, Iowa State Highway Department
H. K. Bishop, U. S. Bureau of Public Roads
G. C. Dillman, Michigan State Highway Department
J. T. Donaghey, Wisconsin State Highway Commission
A. H. Hinkle, Indiana State Highway Commission
H. G. Hotchkiss, Jr., New York State Highway Commission
Wm. Arthur McLean, Department of Public Highways, Ontario, Canada
T. E. Stanton, California State Highway Commission, Sacramento, California
W. A. Van Duzer, Pennsylvania State Highway Department

PART II

PROGRAM OF SECOND ANNUAL MEETING

Thursday, November 23, 10 a. m.

1. Approval or correction of minutes of January 16, 1921
2. Address by Dr. Vernon Kellogg, Permanent Secretary, National Research Council
3. Approval of (1) interim actions of Executive Committee; (2) admission of new member organizations; (3) committee roster
4. Appointment of committee on nomination of officers
5. Report of Director
6. Reports of committee chairmen
    - Committee No. 1, Economic Theory of Highway Improvement—T. R. Agg
    - Committee No. 2, Structural Design of Roads—A. T. Goldbeck
    - Committee No. 3, Character and Use of Road Materials—H. S. Mattimore
    - Committee No. 4, Highway Traffic Analysis—Geo. E. Hamlin
    - Committee No. 6, Highway Finance—J. G. McKay
    - Committee No. 7, Maintenance—W. H. Root

Evening, 8 p. m.

7. Statement by representatives of member societies
8. Address—"The Services of Psychology to Problems of Traffic Control" by Dr. Raymond Dodge, Chairman, Division of Psychology, National Research Council

The presiding officer, Dean Anson Marston, of Iowa State College, Chairman of the Advisory Board, called the meeting to order at 10 a. m.

The minutes of the first annual meeting, January 16, 1922, were approved.

The chairman then introduced Dr. Vernon Kellogg, Permanent Secretary of the National Research Council.

ADDRESS BY DR. VERNON KELLOGG

Mr. Chairman and Gentlemen: I find it my pleasant privilege to extend to you on behalf of the National Research Council a very cordial welcome. The Council has an extremely wide and catholic interest in science, an interest that extends from the science of the structure of the atom to that of the laws of the stars; from that of the nature and behavior of a single living cell to that of the nature and behavior of man. It has an interest in the purest of so-called pure sciences, and in the most practical of applied sciences.

It would be simply a repetition of a truism, or a platitude, if I spoke even a word to you about the importance of science in modern civilization. This matter was brought home to us particularly by the war. The revelations of the war with regard to the importance of science in modern affairs, are still very fresh before us. I have in mind in this connection a particular experience which I had while acting as the chief representative in North France of Mr. Herbert Hoover's Commission for Relief in Belgium and Northern France. I had to live for a number of months at the German Headquarters at Charleville. This was an arrangement so that the great headquarters could keep an eye on these neutral Americans and the work they were doing behind the German front. One thing very much impressed me there, and that was the confidence which the German officers of the great general staff had in science—not that they themselves knew much about it, but they would say to me, when things were going slowly or not just right for the Germans: "Well, just wait, all our scientific men are working, and they will give us something soon to make your eyes stick out." And you will remember that in the early days of the war they did give us several things in the way of application of science to make our eyes stick out.

When I think of your personal interest, the interest you have in a particular field of work, my mind leaps at once to the contemplation of the great rôle that roads have played in the development of civilization. All of you must realize this important rôle that has been played by roads in the migrations of peoples and in the opening up of new regions. Raphael Zon has written, in a well-documented scientific paper, a fascinating story of the relation of forests to civilization. He tells of that period in the development of human civilization when the forests dominated man, and of that next period in chronological sequence when man was trying to dominate the forests, and, finally, of that period when man dominates the forests and makes use of them. Those periods occurred in sequence, but they also exist in all parts of the world today. In certain parts of Africa the forests still dominate man. Réné Maran has written a book entitled Batouala, which has had much attention recently, that gives a picture of human life where human life is dominated by forests. Then there are other parts of the world in which men are now struggling with the forests, and still others in which men have come to dominate them. Recall that beautiful story of French Canada, Louis Hémon's "Maria Chapdelaine," which gives a vivid picture of man struggling with the forests, battling for the land. And finally we have in parts of Europe and in parts of America the situation in which man to-day dominates the forests and makes use of them to his own advantage.

I recall from my own personal experience two pictures of the relation of roads to human life. Many years ago I was in the Samoan Islands. I was very much interested, between doing odd jobs of scientific work that I was there to do, in following up Robert Louis Stevenson's trails in these islands. In going to Vailima from Apia, I found myself, when I was once away from the beach, on a curious little open way that wandered around in the forest. This was a road called the "Road of Loving Kindness." It was built by the natives from the town to the house of the man they loved. It was not a scientifically constructed road; it was a road based largely on emotion. In the spring of 1919 I had occasion to go on a motor trip from Warsaw out to the Polish east front. Poland and East Russia were fighting all along this front, and the American Food Administration was trying to get relief to the starving civilians in that devastated region. This motor trip was made possible by the extraordinary development of roads. That country is made up largely of wild marshes and lonely forests, but through them all, in a straight line almost, ran a military road built by Russia and maintained as a military measure. There was no other way through for miles to the south and miles to the north. There was this one way through, a road built in most thorough scientific manner, not on a basis of emotion, but on a basis of intelligence and scientific knowledge.

But I do not wish to subtract even the least bit from the all too little time you have for your important discussions. And so I merely repeat to you the expression of the cordial welcome of the Council. We are all deeply interested in the work that you have before you; and I hope that you may proceed so effectively with your discussions, and come to such clear understandings that very much good will proceed from your labors.

INTERIM ACTIONS OF EXECUTIVE COMMITTEE

Chairman: There are some interim actions of the Executive Committee which the Director will report.

The Director: The three actions of the interim committee that should be reported are:

1. The admission of constituent membership on the Advisory Board of the Land Grant College Association which represents the group of educational institutions called Land Grant Colleges, one of which exists in each state, and the engineering experiment stations of which spend a half million dollars each year in research of different kinds, chiefly in engineering.

2. The second admitted organisation is the American Road Builders' Association. The object of this association is to acquire and disseminate information regarding roads and highway construction in the states of the union and in the provinces of Canada, to stimulate interest in the subject, and to promote legislative measures tending toward the accomplishment of these ends.

3. The third organization that has been admitted is the National Safety Council which through its Public Safety Division is busily engaged in the study of public accidents and the means of preventing them. It maintains a safety library and is one of the joint sponsors for the proposed color signal code for the American Engineering Standards Committee. Many members of the National Safety Council are also members of the constituent organizations of the Advisory Board.

The interim actions were approved.

The Director: The second group of recommendations is the approval of the committee roster, given in the report of the Director. I do not know that it is necessary to have the Advisory Board approve this formally, but it would be helpful. The motion would be to approve the committee roster as reported by the Director. (See pages 11, 12, 13 and 14).

The committee roster was approved.

NOMINATION OF OFFICERS

Chairman: The third item is the nominations. A Committee on Nomination has been appointed consisting of Prof. Agg, Dr. Dickinson and Mr. Goldbeck.

The next item of business is the report of the Director.

REPORT OF THE DIRECTOR, ADVISORY BOARD ON HIGHWAY RESEARCH[1]

I. THE WORK AHEAD IN HIGHWAY RESEARCH.

(1) Many problems in highway engineering are accompanied by corollary problems in economics of highway transportation. For in-

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[1] Dated November 21, 1922. Mailed in advance of the meeting.

stance: How much can an engineer afford to spend in capital costs of construction in reducing grades? The answer must depend on volume of traffic and on operating costs of road and vehicle. Decisions upon changing second-class into paved roads involve such matters as cost of road maintenance, tires, gasoline, repairs and depreciation to vehicle. Reliable data appear to be largely wanting. The reflex action of improved alignment on change of design of vehicle also suggests itself.

The cost of highway transportation arising from the vehicle, greatly exceeds that from the road.

Great are the possibilities of economies in this industry through research into costs of transportation in the fields of vehicle design and operation. The earnings from improved surfaces are large on roads with heavy traffic: How heavy? Research activities should be pushed. *It is increasingly evident that the highway engineer and the automotive engineer must join forces in coordinated highway research.* Proposals for some joint action that have been under consideration for more than one year should be brought to a head.

It is not too much to say that there must be created a new realm of economic data to quiet opinionated discussion of moot questions in the field of highway transportation. How can issues be settled except on basis of information? College courses in economics of transportation can only be organized following surveys of existing traffic, and collection of data of costs of operation of road and vehicle, maintenance data, study of taxation and benefits. The end must be reached by: (a) Evaluating the present information. (b) Planning new researches where needed. (c) Publishing authentic data as fast as they are accumulated.

(2) The study of methods of financing road construction, and the distribution of the expense among those benefited, awaits fact-finding surveys. The study itself needs the services of trained economists. The sources from which the tax dollar comes, and its distribution among roads, education, charities, etc., should probably be determined. Studies of the effect of highway improvements on land values are needed; and also of the effect of highway improvements upon the developments that have been experienced in typical regions, such as truck farming or resort areas. The results of such studies will be a guide for similar areas under development.

(3) The laws governing the growth and dispersion of traffic, and the mechanics and psychology of safely handling such traffic in congested areas, need study by research methods.

(4) The purpose and methods of, and the instrumental equipment for, basic traffic surveys upon which state construction and maintenance funds may be allocated is a live issue. A simple instrument for automatically counting and weighing traffic is now under development in the Bureau of Public Roads.

(5) The large volume of valuable data, accumulated at the cost of hundreds of thousands of dollars, by the Bureau of Public Roads and in the Bates and the Pittsburg test roads, through studies of soil properties, effect of loads and strength of slab—data that underlie the as yet undisclosed principles of the mechanics of slab design, should be brought together and analyzed to uncover the principles of action. The instrumental equipment and technique in this field represent a remarkable advance in the science of measurement. With the mechanical principles determined, then the engineer can be given formulas for fitting the road to the load. If these principles are still hidden, final coordinated researches should be planned to settle these questions. If it is true, as it seems to be, that stiff slabs on soft subgrades should be thick at the edges and thinner at the center, what should be the proper distribution of the thickness, and how should slabs be reinforced to provide longitudinal stiffness?

(6) The economics of pavement types in specified situations must be learned from carefully gathered data, so that decisions may be made less upon *ex parte* arguments and more upon exact information.

(7) The findings of laboratory tests upon materials of construction should be scrutinized in the light of experience in operation in order to determine to what extent these tests are predictive of service value in the road. Studies of the destructive action of alkali and sea water upon concrete structures are of interest to highway engineers.

All of the foregoing problems are pressing for early solution. Research is not only of direct daily use, it is insurance.

II. ADVANCES OF THE ADVISORY BOARD ON HIGHWAY RESEARCH IN ITS SEVERAL FUNCTIONS.

(1) *To Prepare a Comprehensive National Program for Highway Research.*

The tentative draft of the field of highway research prepared by the Director in August, 1921, has stimulated elaboration of programs both in the field of highway transport and automotive engineering. The committees of the Advisory Board have considered the various programs to determine which of the researches are of most immediate importance. An Advisory Committee on Highway Research has been constituted in the Bureau of Public Roads to advise the Chief of the Bureau as to the allocation of funds for research projects.

The many addresses and lectures of the Director have been of service in stimulating thought upon research programs.

(2) *To Assist Existing Organizations to Coordinate their Activities Therein.*

Since August, 1921, the following organizations have been added to the constituent membership, which now comprises organizations representing all of the important fields of highway research:

American Road Builders' Association
Associated General Contractors of America
Eno Foundation
National Safety Council
Rubber Association of America

The committee on Structural Design of Roads of the Advisory Board has within its membership the chief researchers in the field of design, and has already discussed progress in experimental roads and suggested further researches to complete the whole.

The committee on Character and Use of Road Materials, working through the committee on Tests and Investigations of the American Association of State Highway Officials, has coordinated researches in various state laboratories in this field.

The committee on Economic Theory of Highway Improvement has held a conference in Washington on tractive resistance of roads, at which an understanding was reached as to the respective fields of effort of the highway engineer and the automotive engineer, and the committee has also appraised the progress in this field of measurement.

The committee on Traffic Analysis is considering the purposes and methods of traffic surveys with a view to coordinating the efforts of the State Highway Commissions in this field.

(3) *To Collect and Distribute Information of Completed and Current Researches.*

The office of the Director, through correspondence, has answered a large number of inquiries. As a result of the census of highway research projects in the United States, a list of subjects upon which information is needed has been compiled.

NUMBER OF PROJECTS IN THE DIFFERENT FIELDS OF HIGHWAY RESEARCH.

	Economics	Operation	Design (road)	Design (vehicle)	Construction	Material	Total
Colleges and universities..........	15	4	48	5	3	114	189
Industries.....................	3	2	5	0	1	21	32
Municipalities....................	3	3	8	2	7	10	33
Federal and State Highway Depts..	33	9	53	0	5	105	205
State geologists..................	0	0	0	0	0	17	17
Counties........................	4	0	5	0	1	0	10
Total....................	58	18	119	7	17	267	486

III. NEEDS OF THE ADVISORY BOARD TO ACCOMPLISH ITS PURPOSES.

(1) *Coordinating Research.*

No other organization than the Advisory Board represents so many factors in the problem of highway transportation, or coordinates the work of so many industrial, administrative and technical associations in this field.[1] Certainly some comprehensive and detached agency like the Advisory Board is needed to guide the laying of a foundation of information, obtained by trained scientific researchers, which is necessary for wise judgments upon problems in highway location, construction and operation. Progress in a general educational movement such as this, must necessarily be slow. The effective use of the Advisory Board depends upon a provision for a larger force in the office of the Director.

Nearly 85 per cent of existing projects in Highway Research outside the field of automotive engineering, are conducted largely by governmental bodies, federal departments, state commissions, and land-grant colleges.

(2) *Work of the Research Committees in Evaluating and Planning Researches.*

Money should be available to enable our research committees to meet and deliberate at more frequent intervals, and to procure administrative assistants.

(3) *Collecting and Distributing Information on Completed and Current Research.*

The Advisory Board does not perform research directly; it must depend upon the research of others for both the raw and finished material upon which its deliberations are to be based. It is not likely that there will be funds of the Advisory Board to permit the actual collection and analysis of the results of research on any extensive scale. It is expected, however, that the Bureau of Public Roads will be in a position to undertake this duty. The function of the committees of the Advisory Board will then be to consider the digested results and to use them in their reports.

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[1] If representation were secured from railway and electric interests, the circle of coordination in land transportation would be complete.

It is also expected that the Bureau of Public Roads will publish the digested results of research in the several fields of its activities in the magazine Public Roads which is to appear at the beginning of the year 1923.

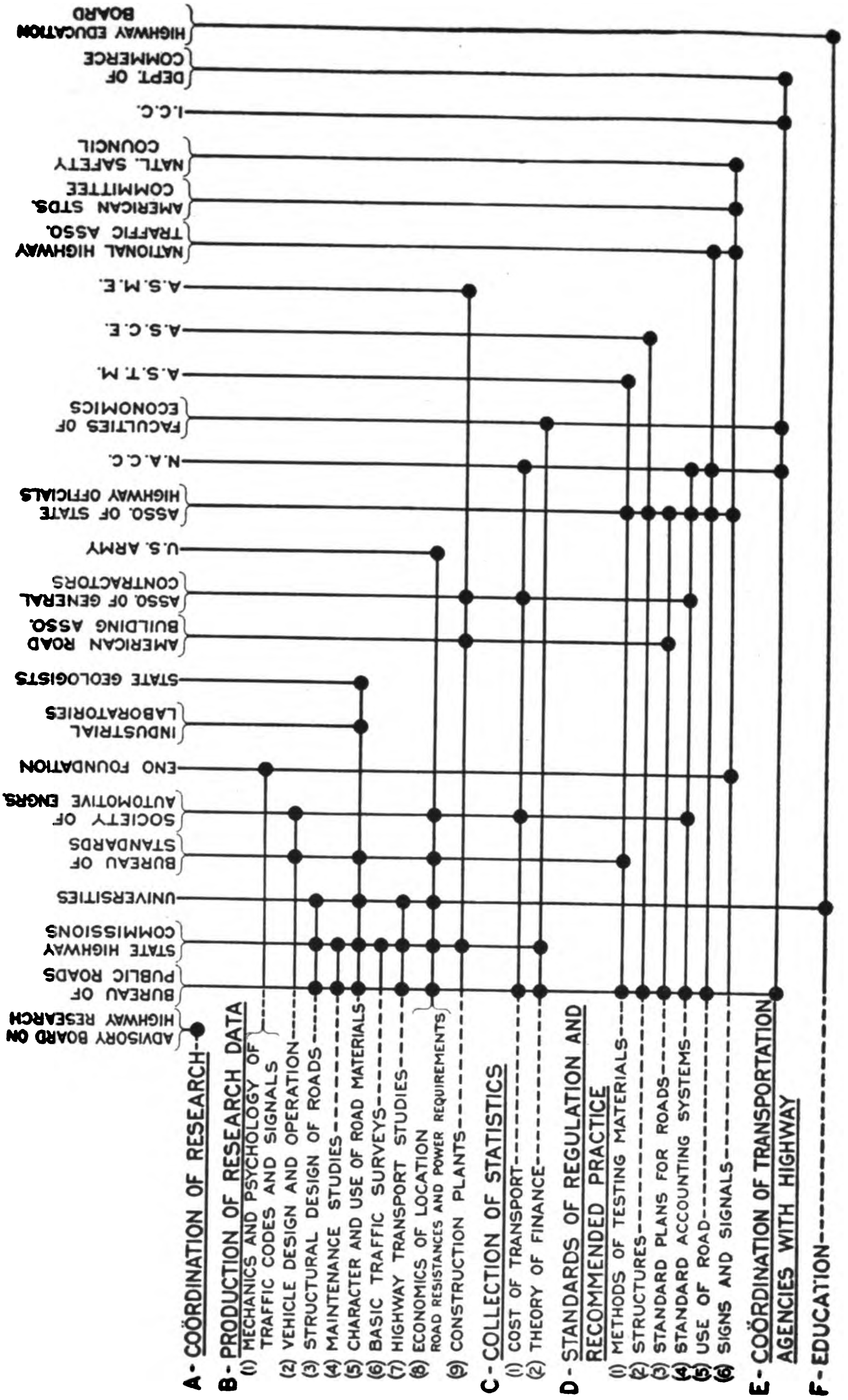
For the purposes stated in paragraphs (1), (2) and (3), a budget of $25,000 a year for a period of five years, plus the research activities of the federal and state organizations and the industrial associations, the analysis and publishing of data by the Bureau of Public Roads, should place the work of the Board on a firm foundation, and attract to its service men who are otherwise loath to take chances on the future.

Large sums of money are now being spent in promotion and propaganda, in conferences and meetings. Large sums are being spent for research. To place the Advisory Board on an active footing requires only the will to do so by leaders of thought in the vehicle and material industries, in the state and federal agencies, the several technical societies, the railroads, and investment bankers.

The Capabilities of the Advisory Board are not taken Advantage of.

With present limited administrative funds, the ideal solution of this problem would be the founding of the work of the Advisory Board by some Carnegie or Rockefeller who can be prevailed upon to become interested in this field which so fundamentally affects the economic life of the country. Several foundations now exist for studies in the field of economics and of government. It would appear that the subject of highway transportation is as important as any one of those fields of effort now well provided for.

The several fields of interest comprised within the work of the Advisory Board and the organizations more directly concerned, are shown in the accompanying chart. The need for a coordinating agency clearly appears and a suggestion for sources of support. No doubt the benefits received would justify expenditures for the support of the Advisory Board by State Highway Commissions. Hitherto some commissions willing to contribute have been unable to do so because of legal difficulties.


A- COÖRDINATION OF RESEARCH
B- PRODUCTION OF RESEARCH DATA
(1) MECHANICS AND PSYCHOLOGY OF TRAFFIC CODES AND SIGNALS
(2) VEHICLE DESIGN AND OPERATION
(3) STRUCTURAL DESIGN OF ROADS
(4) MAINTENANCE STUDIES
(5) CHARACTER AND USE OF ROAD MATERIALS
(6) BASIC TRAFFIC SURVEYS
(7) HIGHWAY TRANSPORT STUDIES
(8) ECONOMICS OF LOCATION
ROAD RESISTANCES AND POWER REQUIREMENTS
(9) CONSTRUCTION PLANTS
C- COLLECTION OF STATISTICS
(1) COST OF TRANSPORT
(2) THEORY OF FINANCE
D- STANDARDS OF REGULATION AND RECOMMENDED PRACTICE
(1) METHODS OF TESTING MATERIALS
(2) STRUCTURES
(3) STANDARD PLANS FOR ROADS
(4) STANDARD ACCOUNTING SYSTEMS
(5) USE OF ROAD
(6) SIGNS AND SIGNALS
E- COÖRDINATION OF TRANSPORTATION AGENCIES WITH HIGHWAY
F- EDUCATION
ADVISORY BOARD ON HIGHWAY RESEARCH
BUREAU OF PUBLIC ROADS
STATE HIGHWAY COMMISSIONS
UNIVERSITIES
BUREAU OF STANDARDS
SOCIETY OF AUTOMOTIVE ENGRS.
ENG. FOUNDATION
INDUSTRIAL LABORATORIES
STATE GEOLOGISTS
AMERICAN ROAD BUILDING ASSO.
ASSO. OF GENERAL CONTRACTORS
U.S. ARMY
ASSO. OF STATE HIGHWAY OFFICIALS
N.A.C.C.
FACULTIES OF ECONOMICS
A.S.T.M.
A.S.C.E.
A.S.M.E.
NATIONAL HIGHWAY TRAFFIC ASSO.
AMERICAN STDS. COMMITTEE
NATL. SAFETY COUNCIL
I.C.C.
DEPT. OF COMMERCE
HIGHWAY EDUCATION BOARD

Acknowledgment.

Without the sympathetic and active support of the Bureau of Public Roads, through Mr. Thos. H. MacDonald, Chief, the Advisory Board would not have functioned. This support has been in money through a contract between the National Academy of Sciences and the Department of Agriculture, and in services of the clerical staff of the Bureau as far as these could be made available.

The National Research Council and the Engineering Foundation have assisted by appropriations to the extent of their ability. Cash contributions from the Connecticut State Highway Commission and the American Road Builders' Association have aided in the work of our research committees.

The experiments of the sub-committee on Tractive Resistance have been supported by contributions from the Portland Cement Association, the Barber Asphalt Company, the States of Massachusetts and Connecticut; and several industries have supplied machines and apparatus. The Quartermaster Corps of the U. S. Army and the Bureau of Public Roads have largely supported the work of this committee. The Massachusetts Institute of Technology has supplied cash contributions and office space. The Mason Laboratory of Yale University, through Professor E. H. Lockwood, has contributed largely through the testing of vehicles under laboratory conditions.

CONFERENCE ON TRACTIVE RESISTANCE.

In view of the several investigations at Cambridge, Mass., New Haven, Conn., Ann Arbor, Mich., Ames, Iowa, and the Bureau of Standards, Washington, D. C., together with previous and projected work in the Bureau of Public Roads, it seemed wise to call a conference of those interested in this field of investigation at the National Research Council. It is hoped that at an early date a circular may be prepared containing the proceedings of the conference, with a summary of the results of the investigations so far obtained. This conference was useful in bringing the minds of isolated experimenters to a common understanding and a common purpose. The following is a summary of the conference:

TESTS OF TRACTIVE RESISTANCE OF ROADS

THE RELATION OF HIGHWAY RESEARCH TO AUTOMOTIVE RESEARCH.

At a conference called in Washington, D. C., July 14-15, 1922, by the Advisory Board on Highway Research, consideration was given to the present state of research on Tractive Resistance of Roads, and to the relation of the highway engineer to the automotive engineer in this field of research.

Those present were:

C. A. Adams
T. R. Agg
H. C. Dickinson
C. R. Ege
H. S. Fairbank
D. C. Fenner
A. T. Goldbeck
W. K. Hatt
Mark L. Ireland
W. S. James
Pyke Johnson
A. N. Johnson
W. E. Lay
E. H. Lockwood
C. J. Tilden

Reports of researches were made by:

T. R. Agg
H. C. Dickinson
A. T. Goldbeck
Mark L. Ireland
W. S. James
A. N. Johnson
W. E. Lay
E. H. Lockwood

A committee consisting of:

C. A. Adams
T. R. Agg
H. C. Dickinson
A. T. Goldbeck
Mark L. Ireland
W. S. James
A. N. Johnson
W. E. Lay
E. H. Lockwood
C. J. Tilden

was appointed to draw up a statement of principles. Their report was discussed and adopted, in substance, in the following form.

REPORT OF COMMITTEE OF CONFERENCE ON TRACTIVE RESISTANCE OF MOTOR VEHICLES.

Definitions:

Rolling Resistance, is the resistance to translation arising from the interaction of road and vehicle—excluding resistances in the engine and transmission system.

> *Explanatory Note.* As ordinarily measured this includes wheel bearing resistance, which in well-conditioned cars should not exceed five pounds per ton. Rolling resistance by the definition also includes the resistance in the framework and spring suspension system of the vehicle arising from the road. Rolling resistance as measured contains various degrees of impact effects and road displacement effects depending upon condition of road and

design of vehicle. Resistance due to horizontal curvature of road should be measured in the experiments.

> *Note.* It is the purpose of tests of rolling resistance to determine the force at the rear axle, or tire periphery, necessary to move the vehicle, as conditioned by road surface, type of road, tire equipment, class and weight of vehicle, etc.

Air Resistance. Resistance arising from relative velocity of air and vehicle.

> *Explanation.* Ordinarily this resistance is included in tested resistance, and should be subtracted to obtain rolling resistance. Investigations are needed to determine the law and coefficient of this resistance for various vehicles.

Rolling and air resistances are those resistances determined when a vehicle is towed with the power transmission mechanism disconnected at the rear wheel. However, the difference between a self-operated and a towed vehicle in respect to tire losses and slipping may make some difference in results, especially at high speeds.

> *Note.* Having the rolling and air resistance, it becomes the function of the automotive engineer to design an efficient vehicle to furnish power for economical transportation over various alignments.

Transmission System Resistance. Transmission system resistance is the force required at rear axle, or tire periphery, to overcome all internal resistance from the clutch to the rear axle.

The transmission system resistance depends upon the gear ratio in mesh and the power transmitted, as well as upon other conditions such as speed, temperature of lubricant, etc. These losses are best determined in the laboratory.

Engine Resistance. Engine resistance is the force required at the rear axle, or tire periphery, to overcome the resistance of engine, including cooling system, fan and accessories.

It depends upon the operation of the engine as regards throttle opening, speed, temperature and mechanical condition of the engine. These resistances are best determined in the laboratory.

Equipment and Instruments. Rolling and air resistance should be measured for basic types of motor vehicles and tractors. For purposes of comparison of economy of types of roads, expressed in gas consumption, time of translation, and other costs of maintenance of vehicle and road, the rolling resistance should be measured to an accuracy of within 5 per cent.

The present state of the art indicates that at low speeds up to 10 miles per hour, a traction dynamometer of the liquid pressure type, or a space-time recorder is considered best fitted for measuring. At higher speeds, a space-time recorder, or a U tube accelerometer is most satisfactory. New instruments should be investigated, especially the torsion dynamometer.

In order to determine safety against skidding under various conditions of brake and tire equipment and road, tests should be made of adhesion of tires on road surfaces under running conditions. The use of an accelerometer with locking of brakes is recommended.

The relation of the Automotive Engineer to the Highway Engineer. The automotive engineer needs data of rolling and air resistance rather than data of gasoline consumption from road tests, since the latter data depend upon individual characteristics of vehicle used, carbureter, habits of driver, etc. Having the power factors, the automotive engineer will design the plant to furnish the power required.

From the standpoint of the highway engineer, a problem like the following is set:

A reduction of grade of 4 feet will reduce energy required an amount of 8,000 ft. pounds. What will this be worth in saving of gasoline and other operating expense for traffic considered? Will the solution be for cars as at present built, or for cars using these roads 15 years from now? The mutual relation of highway and vehicle is expressed in the effect of low grades on changes in engine design and power requirements of car. Inasmuch as the large expense of highway transportation is in cost of operation of transportation rather than in fixed charges and maintenance of road, the investigation of costs of operation of traffic is particularly needed.

It is estimated that a 5 per cent grade on a hard-surfaced road is not considered excessive for passenger cars, and 2 per cent to 3 per cent for heavy capacity trucks.

The fuel cost and time required, as affected by type and design of surfaces and grades, is measurable by experimental methods; and the depreciation of the vehicle, and other maintenance costs should be evaluated from a study of the statistics of motor vehicles obtained in actual operation.

SUGGESTED OUTLINE OF APPROPRIATE ACTIVITIES IN HIGHWAY RESEARCH.

The following suggested outline of appropriate activities in highway research is submitted by the Director:

A. Research for Automotive Engineer.

1. To determine fuel, oil and grease consumption and power development of vehicle and from these to calculate the per-

formance on various surfaces and grades, and the excess power for moving trailers.

2. To study the effect of improved grades on the design of the power plant of the vehicle.
3. To consider the design of the vehicle in order to impose on the road the minimum loads for specified capacity of vehicle.
4. To study the lighting system of autos with a view to safety; and the mechanisms indicating intentions of the driver.

B. Research for Highway Engineer.

1. To find rolling and air resistance of motor vehicles at various loadings and speeds on typical road surfaces and curves; limit of adhesion.
2. To determine the loads imposed on road surfaces by various vehicles, with various tire equipment at various speeds.
3. To discover the stresses and strains acting in various road surfacings under the expected loads, and the properties and improvement of subsoils.
4. To determine capital and maintenance costs resident in the road.
5. To determine the laws governing the increase of highway traffic by basic surveys of flow of traffic in typical regions.

C. Research for N. A. C. C. and Automotive Associations.

1. To assign schedule cards to a selected group of, say, 200 passenger drivers for each condition, to obtain operating expenses on the average for:
    - (a) Three classes of cars
    - (b) Regional conditions
        - Dirt and gravel roads
        - Macadam roads
        - Paved roads
    - (c) Topography
        - Level
        - Hilly
2. To study records of truck and passenger bus fleets to obtain similar data.

D. Locating Highway Engineer.

Given, road resistance, power available at wheels, speeds, fuel, oil, and grease consumption, tires, repairs, driver's time, depreciation, overhead, expected traffic,

To find—relation between capital costs of construction and operating expenses on roads of various surface and grades (length and rate).

E. Federal Agencies.
  1. To study movements of commodities and passengers by highway and railway, in the interest of coordination of transport.
  2. To study the financing of highway improvements in the light of experience and science in related fields of financing of public improvements.
  3. To study the effect of highway improvements on regional industries.
  4. To study the effect of highway improvements upon general productivity of men and industries.

F. Advisory Board on Highway Research.
  To evaluate progress in the several fields of highway research by an analysis of completed and current projects; to outline needed researches; to assist existing organizations to correlate their work in the light of a comprehensive program; and to publish bulletins of information on methods and technique of research, and on progress in the several fields.

PUBLICATIONS.

A bulletin of the National Research Council was sent to press on October 3, entitled "Highway Research Projects in the United States; Results of Census . . . ," and will be distributed at the meeting of the Advisory Board. This contains a description of some 486 research projects in highway engineering. The bulletin shows those fields of highway research which need early occupation, and will serve to put into communication with each other those researchers who are working in the same field.

Undoubtedly highway engineers are confronted with questions which will be answered only after several years of isolated experimentation. A knowledge of similar work and coordination of efforts of the several states will produce early answers and economize expenditures, not only in research, but in construction and operation of highways.

Chairman: I wish to call attention to the roll of member bodies. It makes quite a list and perhaps it might be helpful to have this list read at this time so that we may have brought before us a perspective view of the entire present membership of the Advisory Board. (List of membership read by Dr. Hatt.)

Chairman: We now have complete representation of transportation interests except in the line of steam and electric railway interests, and

I hope at some time we may have representation of these also on the Advisory Board.

I think the work of the Advisory Board is becoming definite. Our field is being cleared and we know better now what we are doing than we did before.

REPORTS OF COMMITTEES

REPORT OF COMMITTEE NUMBER 1, ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT.

There is appended a brief statement relative to the present status of each research project that has been carried out as part of the program of the Committee. It will be noted that real progress has been made during the past year and that the results obtained by several experimenters are either already in printed form or will be published shortly. Unless unexpected delays occur, all of the projects now under way will be completed by the end of next March. That does not signify the exhaustion of the subjects for research, but that one phase of the work has been completed.

In connection with the investigations of tractive resistance, there remains some work to be done with a transmission dynamometer and with various combinations of trucks and trailers. The study of wind resistance must be extended to several additional types of vehicles. It will be desirable to secure additional data on resistance due to curvature and on the relative slipperiness of pavements.

It is believed that sufficient information has been secured, regarding the effect of grades on fuel consumption, to permit the establishment of a tentative theory of grades. Additional data are needed to enable an engineer to estimate the decrease in the cost of transporation resulting from grade reduction.

No progress has been made on the project for the establishment of capital and operating costs for vehicles and for highways. The data relative thereto are so widely scattered and so fragmentary that it will require another year to secure enough information to justify a progress report. It is upon this subject that the Committee will concentrate effort during the coming year.

By mutual agreement between the Advisory Board on Highway Research and the Society of Automotive Engineers, all research having to do with the internal resistance of motor vehicles has been delegated to the Society. All efforts in that direction have been discontinued by Committee Number 1.

Inasmuch as the Chairman of Committee Number 1 has for three years, in season and out, urged upon individuals and upon associations the necessity for research in the highway field and has given much time to the promotion of highway research, a few comments of a general nature seem allowable.

Those in touch with the developments in the highway field can not fail to sense the almost revolutionary changes in highway practice since the World War. A part of this progress can be directly attributed to the dissemination of data obtained in highway research and a part to the stimulation of highway engineers arising from their contact with highway research. But we have not yet arrived nor anywhere nearly arrived at a solution of many of the problems pressing for solution. Research of many kinds will be required for years in connection with the highway construction program. Such research will not be prosecuted on a scale commensurate with the need unless there is an aggressive, authoritative and well-financed agency continuously engaged in fostering highway research. A fact that must not be lost sight of is that the benefits of highway research reach all of the people of our country. But because those who benefit are obviously unable to appreciate what has been accomplished by highway research, popular support can not be secured.

In the industries, the pressure of competition and the search for better or cheaper methods are ever present factors that tend to stimulate research work. But in the highway field the commercial consideration is lacking and research will lag unless the need is kept constantly in view. This function has been assumed by the Advisory Board on Highway Research of the Division of Engineering of the National Research Council, and for two years rapid progress has been made toward establishing a national program of highway research.

To secure recognition of a need for research is vastly easier than to get research agencies actually working on pertinent problems. That can be done only by an agency having at its disposal funds with which to assist in the prosecution of research.

In attempting to secure the cooperation of men qualified to direct research in the solution of some of the problems before the Committee I have interviewed a score or more of investigators. A few have undertaken research problems and carried them through. Usually they have done so at a wholly unwarranted personal sacrifice. They have given to the work time and energy and sometimes funds that should have been devoted to other purposes. In many other cases able men have declined to undertake research work for the Committee because they did not feel disposed to do so at the sacrifice of their regular vocation.

It should not be necessary to ask technical men to give gratuitous service to the public in connection with highway research; nor can the urgent requirements of the highway field be met in that way.

There will long continue a need for a central agency that can promote highway research of the right kind; that can secure the proper research agencies and guide them in their work; and that has funds at its disposal for compensating the individual investigators when they can not secure the compensation otherwise.

PRESENT STATUS OF PROJECTS OF COMMITTEE ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT.

Tractive Resistance. A preliminary report covering the earlier work at Ames is now in press. The later work, which is being conducted in cooperation with the Bureau of Public Roads, is 85 per cent completed and will be covered by a report which is expected to be ready in March.

The project of the University of Michigan and the Michigan State Highway Commission has been completed and is now being printed for distribution.[1]

Major Ireland has completed the Cambridge project and a special report thereon will be forthcoming from the sub-committee in charge.

It is believed that these reports will cover the present requirements in this field and no new projects are contemplated until the need becomes apparent.

Grades. A final report on the Ames investigation of highway grades is appended. This phase of the project will be discontinued, but new studies of certain elements of the problem will be inaugurated next year.

The report of the University of Michigan and the Michigan State Highway Commission already referred to also includes studies of grades.

Wind Resistance. The investigation of wind resistance has been greatly delayed from various causes and the time of its completion is problematical. A preliminary report is to be issued soon.

Capital and Operating Costs for Vehicles. Little progress has been made this year, but the way is clear for rapid progress next year.

Capital and Maintenance Costs of Highways. This work is just being organized and should proceed rapidly during the coming year.

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[1] Michigan State Highway Department Investigations of Truck Performance on Grades. By Victor R. Burton, Dist. Engr., Mich. State Highway Dept., and Walter E. Lay, Asst. Prof. of Mechanical Engineering, Univ. of Mich., by direction of Frank F. Rogers, Mich. State Highway Commissioner.

I wish to mention the general activities of Committee Number 1, and then to discuss in detail one of the projects.

One line of investigation has been in the field of tractive resistance at the Iowa State College. The first attempt in that direction was to establish the outside limits of tractive resistance and then to determine values somewhat more closely. That project was completed early this year and the results are being published in bulletin form, and will be ready for distribution within a week or so. (See Engineering News-Record, Dec. 7, 1922.)

It was then necessary to investigate certain phases more in detail. A cooperative agreement for this work was entered into with the Bureau of Public Roads. The work has been carried out since March very largely with a certain type of vehicle both loaded and unloaded, using both solid and pneumatic tires, and the test has been extended to cover every type of vehicle in the vicinity of Ames. It appears that the work will be completed by the end of this year, and the bulletin will be in form by March. Some further tests for the purpose of checking up certain details which affect tractive resistance are to be run next year, using a transmission dynamometer.

The project at Cambridge which was mentioned by the Director was supervised by a special sub-committee, and a report thereon will be expected from that sub-committee.

Another problem is in the economics of highway grades. Reports are in form for publication at this time. It is hoped that there will be an approach to an establishment of the theory of economic grades. By agreement between the Advisory Board and the automotive engineers, investigations of gasoline consumption in road tests—only a small amount of this work was under way—have been discontinued by Committee Number 1, but are being carried on by the Society of Automotive Engineers.

I would like to ask Mr. Manly to say a word or two relative to the determination of capital and operating costs of roads to be taken up by Committee Number 1.

Mr. Manly: As the representative of the Society of Automotive Engineers on the Committee on Economic Theory of Highway Improvement, I have undertaken the investigation of a certain portion of the program agreed on, especially that bearing on the "Relation between character of road surface and cost of vehicle maintenance." In this work the principal point I have been giving attention to is the study of the interaction of the motor vehicle on the road and the road on the vehicle, especially as affected by the tires and spring suspension. The most difficult part of the work is properly to analyze the problems so as to determine the proper design of apparatus to get the really necessary data in such form that it can be interpreted. We have just reached the point now where we think we are getting the problem properly analyzed and the apparatus properly designed, and we hope in the spring to carry out some actual tests and get some data that can be accurately interpreted. I think it will take much less time to get the test data than it has taken to get the problem properly analyzed and the apparatus so designed as to give sufficient factors to enable them to be properly evaluated.

Prof. Agg: The work on a study of the economic theory of highway grades has now been completed, which does not mean that we have exhausted the subject, but simply have arrived at the place where we can publish the results. (See Engineering News-Record, January 11, 1923.) The work will be continued at Ames and perhaps elsewhere. We expect to arrive at a place where it will be possible to state the theory in proper form. The University of Michigan has a bulletin in press to be issued about December 1, the result of a cooperative research on economic grades between the University of Michigan and the State Highway Department of Michigan. This bulletin will be the first on this particular subject.

We expect to issue a bulletin on this subject from the Experiment Station at Ames some time after the first of the year. At Ames vehicles were equipped with a meter which would enable us to plat a curve of performance of vehicle for comparison with the road profile. Tests were made over different sections of road with different rates of grade. Profiles of road surfaces and gasoline consumption were platted in an attempt to establish a grade at which the amount of gasoline used would be greater than that used on straight-way level roads. One important point came up early in the experiments, viz., that in certain grades and successions of grades the actual fuel consumed in traveling a hilly road was less than in traveling on a zero grade. Under other conditions that is not true.

We have attempted to determine the limits of a grade that would be economical and the sums of money that can properly be spent to reduce to the economical maximum grades now above that maximum. I think I can illustrate this work better with the lantern slides than in any other way. [Presents discussion.]

Prof. Blanchard: The report referred to by Prof. Agg is entitled Michigan State Highway Department Investigations of Truck Performance on Grades, and was undertaken in joint cooperation with the engineering departments of the University of Michigan and the State Highway Department, by Prof. Lay and Mr. Victor Berger, District Engineer. This report occupies seventy pages and will be available in the form of a reprint or as a part of the Proceedings of the Eighth Annual Conference on Highway Engineering. Those Proceedings will also contain the report of the Michigan Investigation covering the dust prevention and preservation of gravel roads which extends over the entire season of 1921. Anyone who desires a copy of these reprints or complete proceedings may obtain them from me. They will be received from the printer on December 1. [At the request of Prof. Agg, Prof. Blanchard read the summary.]

Chairman: This report is open for discussion. One of the questions arising in the mind of the automotive engineer is: How safe is it to base long-time conclusions as to grades on the figures based on fuel consumption because of probable changes in fuel consumption on different operating car factors.

Prof. Agg: I undoubtedly did not make that point clear. We do use fuel consumption to determine the law of grades. However, the final value of a grade depends on the tractive effort of the vehicle which is something the automotive engineer can determine for his particular design. The power of the vehicle and the resistance of the road surface will have to be determined by experiment. The fuel consumption element does not enter in except that the consumption was used as a factor for establishing the effect of grades on consumption of fuel. My first idea was to put this in terms of fuel. After Dr. Dickinson called my attention to the disadvantage of this index, we changed over to a power index.

Chairman: This matter is up for full discussion, and I should like to have any questions brought up.

Mr. Cummings: I should like to ask the chairman of the committee what consideration he has given the alignment of roads.

Prof. Agg: That work is under way, but we have no definite results.

Mr. Crane: This question of alignment—vertical and horizontal alignment—seems to have a large bearing on the economics of highway location. Another important element is the time of transit. An engine of the automotive type has a constant standby loss when operating and the use of gasoline enters strongly into the operating cost, as well as the cost of labor which is a function of the time. Any study considering purely the tractive resistance on hills will be of limited value only. A study of curves as they may affect the grade situation, would also be required. Curves add to danger and tend to slow down operation.

Mr. Crane: I may say that in the gasoline economy tests that were run ten or fifteen years ago, where the four-cycle type of engine, the almost universal type at the present time, was used, the custom was to operate on level roads in a manner similar to the method of operation ordinarily used in a rolling country. The car would be accelerated with wide-open throttle until a speed of about 25 miles per hour was reached, and then would be allowed to coast with the engine shut off until it almost reached a standstill. The cycle of events would then be repeated.

The reason for the low fuel consumption obtained by this method of operation lies in the character of the fuel consumption curve of the four-cycle type of engine. This type of engine shows the lowest consumption per horsepower with wide-open throttle and a very much higher rate of consumption per horsepower as the throttle is closed more and more. This is not true of engines of the two-cycle and other constant compression types.

Mr. Manly: An impression was made on my mind in connection with this matter that seems to me important—that is the matter of developing a formula with the effect of curvature taken into account. I was not much surprised that Prof. Agg has not taken curvature into account. The important thing it seems to me is that we should recognize that we probably will not be able to determine a completely comprehensive and exact formula right away; but that if we can get some of these partial formulae on paper and get them discussed, various points of view will be brought definitely before a large number of people, and the effects of all the different systems of testing brought out. We will then make more rapid progress than if we try to solve the whole problem all at once. Scarcely any combination has more factors in it than an automobile and a road. We are not going to be able immediately to get a formula that will enable us to go out and tell the engineer exactly how to build the most highly economic road for all conditions. We may, however, be able to get a clear view of how to attack the problem; and the important thing is to get any problem properly analyzed. To do this we must separate out some of the secondary problems and determine some of the different factors and then get positive and definite results on those. I do not expect that in this part of the work we are doing we shall get any results that we shall be able to interpret into immediate design formulae, but we are at any rate finding out some of the defects of some of the apparatus heretofore thought suitable for such work. We started out using the seismograph and spent a lot of time and money only to get a lot of results that could not be interpreted. The important thing to do is to get the work under way and the results placed before others so that the cumulative effect of the experience and criticism of various investigators may be brought to bear on the problem.

Prof. Agg: The director asked me to mention briefly another line of information that came out incidentally in this problem. In attempting to find out the effect of grade on fuel consumption we had to determine the fuel consumption on zero grades. We were unable to find the grades we wanted on paved roads. Some were on gravel roads, and some on paved surfaces such as concrete and the bituminous types. We found that on gravel roads at zero grade, the fuel consumption was greater than on certain hills. At first we thought that this was an error, but we checked it up and found that it was actually true. We then went to some pains to compare fuel consumption on different types of roads, and also to compare ratios of fuel consumption with ratios of rolling resistance. If the rate of fuel consumption on a good paved road were taken as unity, the rate on a gravel road would be about 1.4 and on earth roads in average condition 2.0. Approximately the same ratio exists between the measured tractive resistances. Here is something that is pretty definite and tangible. If there should be improvements in the automobile and truck this difference in fuel requirements for the different types of road will still exist although the actual rate of fuel consumption will be somewhat different from what we have measured at the present time. We can pave certain of the roads in Iowa and pay for the work in eight years from the saving in fuel consumption over the present road based on the present price of fuel and present efficiency of the motor vehicle.

Chairman: From the standpoint of the construction engineer we are finding these results of immediate use. In this connection I am going to ask Dr. Dickinson to give us a further discussion of the work of the subcommittee on tractive resistance for the reason that Major Ireland, who was to give an address this evening, will not be here owing to the fact that he has been transferred to the University of Michigan. So I am going to ask Dr. Dickinson to give an account of the work of the sub-committee on Tractive Resistance.

Dr. Dickinson: I should like to think the matter over a little.

Dr. Hatt: I regret very much that Major Mark L. Ireland, Q. M. C., is not able to appear here tonight. He has been transferred from Cambridge, Mass. to the University of Michigan to study under Prof. Blanchard. Major Ireland has been director of the coöperative research on tractive resistance at the Massachusetts Institute of Technology. His research has been of large volume and of very great value. A report of the results of this research is expected in the course of a couple of months. Dr. Dickinson has been an adviser in this research.

Chairman: We will allow Dr. Dickinson to think the matter over. In the state of Iowa we have just made a beginning of paving our principal roads. We have about six per cent set aside in a system of primary roads which connect towns of 1,000 or more population, and is so located that a considerable majority of the population of the state, about 75 per cent, is located within a mile or two of a primary road. Practically 80 per cent of the traffic of the state uses these primary roads. There should be at least 6,000 miles paved. The people of the state of Iowa may or may not be able to pave them in the immediate future, but we know from the work which has been done, that it would be saving money to pave these roads on the basis of fuel consumption alone. The people will eventually pay out more money in the course of ten years—in some cases in a shorter time—to operate these roads with gravel or earth surfaces than it will to pave them and operate them as paved roads. One year ago we could not prove that statement. Today we know it would be economical to pave those 2,000 miles of primary road system.

The report of Committee No. 1 was received.

Mr. Goldbeck, Chairman, read the following report:

REPORT OF COMMITTEE NUMBER 2, ON STRUCTURAL DESIGN OF ROADS.

The first meeting of this Committee on Structural Design of Roads, of the Advisory Board on Highway Research, was held at the National Research Council Building, Washington, D. C., October 25, 1922, with A. T. Goldbeck, Chairman, presiding.

Those present were:

Lloyd Aldrich
H. C. Berry
C. N. Connor, representing C. M. Upham
F. H. Eno
A. T. Goldbeck
C. A. Hogentogler
C. Older
H. G. Shirley
E. B. Smith
C. M. Strahan
E. W. Templin
H. M. Westergaard

Dr. W. K. Hatt, Director of the Advisory Board on Highway Research, was also present and discussed the function of the Committee.

The object of the Committee is set forth as follows:

To expedite the development of the fundamental principles underlying structural design of roads, for the accomplishment of which the following procedure is suggested:

1. Outline the general problems involved in road design for the various types of roads.
2. Outline the specific researches needed.
3. Review the status of present knowledge and thus eliminate this from the necessary researches.
4. The problem having been defined, a suggested research procedure or project statement should be outlined in detail for each problem, in accordance with a standard form.
5. The problems thus outlined should be reported to the Highway Advisory Board for publication to the end that research institutions might select such of these researches as might be feasible for them to perform.
6. As the results of researches become available, they should be reviewed and placed in their proper relation to other existing data and whenever possible analyzed with the goal of rational design in view.
7. Advice should be given to research agencies whenever called for.
8. Reports should be made annually on the existing status of knowledge bearing on highway design, with a statement of the field still to be covered. In accordance with the proposed activity No. 8 the following annual report is submitted.

The three principal investigations carrried on for the purpose of securing information which would lead to the rational design of roads, are the Pittsburg test road, in California; the Bates experimental road, Springfield, Illinois; and the Bureau of Public Roads experiment at Arlington, Virginia.

On the Pittsburg road, concrete slabs of different thicknesses and varying reinforcements were compared under action of heavy motor truck traffic.

On the Bates road, about 75 different types of surfaces were subjected to the action of heavy motor truck traffic. In this road were represented such types as plain and reinforced concrete of different thicknesses, monolithic brick, bituminous filled brick on concrete and macadam bases, and bituminous concrete surfaces on concrete and macadam bases.

At the Arlington experimental farm various types of surfaces, such as plain and reinforced concrete, bituminous tops on concrete, macadam on black bases represented by blocks 7 ft. square, are being subjected to blows from an apparatus delivering impacts similar to those which might be expected from motor truck wheels.

In addition to the traffic runs on the experimental roads, observations were made for deflections, deformations, movement of slabs due to warp, and so forth.

On the Bates road, deflections and deformations were secured from both moving and static loads placed at numerous positions on the slab in order to determine what position of load creates the greatest stress in the slab. Not only is there the actual dropping of a weight on the slabs at Arlington, but an instrument records also, the intensity of the blow, while other instruments indicate the deflection of the slab and the stress in the extreme fibre.

In addition to these investigations, and as supplements to them, there are being carried on at the testing laboratories at Springfield, Ill., Purdue University, and the University of Maryland, investigations of fatigue of concrete. Preliminary reports of fatigue investigations indicate that up to a certain per cent of the ultimate load, concrete will withstand any number of repetitions of stresses, but beyond that percentage a definite number of loads will cause failure. This information is valuable because it indicates what a safe load on a road should be. For instance, in the traffic tests, the slab may not have failed if the stress produced in the slab by the load was in excess of the critical fatigue per cent limit, but it can be assumed that that slab would fail if sufficient number of repetitions of the load were given it.

At Arlington also there is being carried on a study of bituminous surfaces with a view to eliminating or controling corrugations under traffic; also a study of the wear of concrete made from different aggregates. We know that when concrete roads were first constructed, in many cases surface deterioration developed which was attributed in some cases to improper aggregate. By paying special attention to the selection of aggregates, the surface wear abrasion has now been eliminated. This test is carried on with the possibility of opening up wider fields for materials for aggregates.

While the final reports of the Pittsburg test road, the Bates test road, and the Arlington experiments have not as yet been published, from preliminary observations it can be said that under loads the least resistant part of the slab is the corner. That the position of the load which causes most serious stress in the slab is at the side edge, either at or near the corner. It has not been definitely settled whether the greatest tension is produced in the top or the bottom of the slab. An unsettled question also is that of the impact effect of moving vehicles on the slab. We have information to show that under moving loads the actual deflection at one point is less than under the load remaining at rest at that point. This does not indicate, however, that the stress is less under the impact, since the area of distribution of the deflection might be different under impact and static loads. This phase is being investigated.

From the preliminary reports of the experimental roads it would seem that the best way of increasing the strength of the slab without increasing the total amount of concrete, would be to thicken the edges. The point to be investigated is the determination of the relation of center to the edge thickness so that the strength of the slab will be more or less uniform. The question of reinforcement also has not been settled; that is, should the principal reinforcement be longitudinal or transverse, and is it better to have one layer or two; and if one layer, where should it be placed, top or bottom of the slab? With this question of proper reinforcement is also connected the strengthening of the corners. On both of the test roads it was found that the corners were less resistant to traffic at night than in daytime, the reason for which (warping) has been frequently discussed. It is possible that proper reinforcement will considerably reduce this warping which we have reason to believe occurs in the main only very near to the corners. Proper reinforcement also will strengthen the corner by distributing the load to the adjacent slab. After the direction and position of reinforcement have been determined, the next question to be settled is how this reinforcement should be distributed; for instance, if a certain section of steel is required, should it be all in one bar or will several bars answer the purpose better?

Connected, of course, with all these questions is the relation of the subgrade to the slab—investigations concerning which were carried on at Pittsburg, Bates and Arlington. If it is true that a soil of low moisture content offers better support than one of higher per cent of moisture, methods must first be evolved by which moisture content can be stabilized. After these methods have been perfected their cost must be compared with that of additional thickness of the road necessary to overcome the faults of the subgrade without treatment, to determine whether, economically, it is advisable to treat the subgrade or increase the strength of the slab.

Another phase of the question being studied is the effect of the variations in road surfaces which not only cause inconvenience to the traveling public, increased tractive resistance with a consequent added expense for fuel and oil and deterioration of machines, but also cause the road slab itself to be subjected to greater forces than would one of perfect smoothness. Investigations have been carried on for measuring both variations of the surface, and the effect of these variations on truck wheels passing over the surface. This study concerns not only ordinary construction, but also methods for maintaining the surface. In the case of flexible types, the magnitude of corrugations will be an indication of when it will be economical to renew the surface. Take for instance a 2" bituminous top on a 5" concrete base. After the resistance of this surface to loads has been determined, there should then be determined how great a variation may occur in the bituminous top, before the impacts caused by these variations are sufficient to endanger the 5" concrete base. Or is it a question in design of the road? How much extra thickness of base should be provided to take care of the impacts which can be expected from variations which occur in a certain number of years?

In all of this work it has been necessary to develop instruments. One of the biggest drawbacks to measuring stresses has been the absence of an instrument for measuring deformation of fiber directly beneath the moving wheel. There seems to be a good possibility that the Bureau of Public Roads will in the near future furnish such an instrument. Rapid progress has been made in the development of apparatus for securing information on subgrade conditions, as well as on instruments for securing deflections, and roughness of surface measurements.

In the contemplated extension of the Pittsburg tests, bituminous as well as concrete types will be observed. In the new Bates sections, types having thickened edges will be used.

Efforts have been confined not entirely to artificially loaded road sections but also to roads carrying regular traffic. In New York State and in Maryland, concrete roads of various ages have been studied by means of samples taken from the surfaces. Asphalt surfaces of various ages and under different traffic conditions have been studied in much the same manner, samples having been secured from the larger cities such as Baltimore and New York. Top-soil and sand-clay types under varied maintenance and traffic are now being studied in Georgia and North Carolina.

When the final results from such activities as have been described and those supplementary to them have been properly analyzed and interpreted, it is felt that the accurate design of a road surface for given traffic conditions will be reduced to an ordinary technical problem.

Meeting adjourned at 12.30; and was called to order at 2 p. m.

Chairman: I wish Mr. Goldbeck would discuss subgrade investigations.

Mr. Goldbeck: Dean Marston has reference to the series of tests being conducted at Arlington in which a number of concrete slabs about 10 feet square are laid on subgrades drained in a variety of ways. For instance, one slab is laid on the subgrade that has not been disturbed, and in other cases on subgrades treated with water-gas tar to a certain depth. We have done all we could to keep the water out of the subgrade by drainage. So far as present knowledge is concerned, there is no substantial difference in the amount of moisture in those subgrades,—that is, the water that enters by vertical capillarity. I do not mean that the side drains are not effective in removing water from coarse soils; but they are not effective in taking care of the water that enters by vertical capillarity. When freezing takes place in these soils, they will expand, and under drying conditions, they will shrink, as has happened in California. The subgrade dries out and shrinks more at the side than at the center and leaves the side of the slab unsupported.

Chairman: Will the chairman of the Committee on Soils of the American Society of Civil Engineers, Mr. R. A. Cummings, contribute to the discussion?

Mr. Cummings: Frankly I would rather confine my remarks to the report of the Committee. From my own experience in similar work I appreciate the personal sacrifices and efforts required to lay down such a comprehensive program as that which has been presented, and the Committee is to be commended.

But I apprehend that there is danger and I believe a disposition also to concentrate on certain phases possessing popular appeal. The Committee has *indicated this objection* by their elaboration in the study of road pavement slabs, etc. This is to be deplored, because the deportment of concrete road slabs under a live load appears to me to present the problem of the reaction of the foundation soil. The Committee will miss an objective and fail in making fundamental progress unless very earnest studies of the soil itself are undertaken at once. I am fully aware of the preliminary and very creditable publications issued in the past which are interesting contributions; but they are incomplete and do not fulfil their purpose.

Of course the effect of impact due to irregularities in the surface of the road and other necessary investigations connected with direct load action, should be undertaken. But it is certain that the effect of the load reaction of the soil is none the less important. I fear that the time and money spent in securing data so refined that it must be subject to assumptions in interpretation in order to be suited to practical application, is misdirected effort.

A comprehensive knowledge of the soil itself and of its physical characteristics in relation to the distribution of stress is seriously needed. To this end real contributions for serviceable progress are in universal demand.

I cannot plead too earnestly for cooperative efforts in this direction. I respectfully urge that the recommendation of the Advisory Board embody this plea, and urge the cooperation of associate bodies.

Mr. Goldbeck: I am sorry the committee report gave that impression. As a matter of fact, we have the soils very actively in mind. For instance, already we are conducting laboratory tests to determine the characteristics of soils which make for bearing value and various other characteristics which we think we ought to take into consideration. Already field tests are being conducted in California in which an attempt has been made to change the characteristics of the soil as they exist by the use of admixtures. We thoroughly realize the necessity of looking into the soil. We are not neglecting the subgrade.

Chairman: I think perhaps the chair was a little responsible for giving the wrong impression. When I said the soil was not capable of carrying any load, I was thinking especially of the Illinois investigations. Mr. Older says he has a formula based entirely on the thickness of an unsupported slab. I also had in mind an address by Mr. Benedict of the Illinois Highway Commission in which he showed us a slab with a tent roof over it and the subgrade, to keep the soil dry, and another slab surrounded by a ditch filled with water. He said the tests of moisture under the first slab showed a larger percentage of moisture than in the second for some days.

Mr. Blair: I meet a good many engineers throughout the United States yearly who think, and honestly believe, that many subgrades cannot be drained. In view of that, I am wondering whether we might not take a lesson from some of the experienced farmers, who construct drainage systems which are not wholly for the purpose of taking the water out, but also to let the air in. If it is true that there are plastic soils that we are unable to drain, I imagine we could never make a brick. We do saturate the clay with water in the making and formation of the brick creating a most plastic condition. We know very well that when the air surrounding the brick contains its maximum amount of moisture that no more moisture can be extracted out of that brick, unless a new supply of air is furnished to receive additional evaporation. I do not wonder at this experiment of Mr. Benedict's at all. If the soil in either case is holding all that can be cared for and there is no opportunity for injecting air, of course it is going to remain moist. I think it is well for us to get back and study the subject of the subgrade and stabilize it. We ought to take into consideration some of the elementary facts of physics and we shall then be able to make some progress. Successful road-building will depend upon the solution of these problems, of which we know but little. We must know. Otherwise we are going to spend millions of money without results. I know that the construction of the road between Cleveland and Akron, Ohio, has a 6-inch concrete base, excellent work, one portion a brick surface, another portion of bituminous macadam surface. It all went the same way—to destruction. I made a topographical survey of that surface and I found that 1,800 acres of rainfall had to pass underneath that road at a point where the greatest amount of destruction occurred. I found that, in addition to the quantity of water that had to pass under the road, the disposal point at 27 inches below the top of the road became stagnant so that there was a water-soaked road continuously winter and summer. I am not altogether a believer in the side open ditch for the purposes for which it is built. Outside of the physical objections to it, it is dangerous to traffic. I do think, that while it may incur considerable expense, we may well consider whether it is economical to place for the disposal of water a deep tile drain that is working all the time summer and winter rather than spend a lot of money for side open ditches that function but a part of the time.

Chairman: The Iowa State Highway Commission has confidence enough to undertake the construction of over a thousand miles of tile drains on the primary road system. We realized that the important function of tile drainage is to remove the surface water. I would like to ask others for discussion of these matters.

Prof. Blanchard: Many of us are looking to the committee of which Mr. Goldbeck is chairman for the fundamental principles of the design of rigid foundations for pavements and structures. I should like to ask how far he feels that the committee has gone in the problem of a single concrete pavement 8 feet in width which would be covered practically by a large truck as far as overall is concerned. Leaving out of consideration the more complicated design of cantilever beams and beams that would have to be considered in a wider pavement, it would be of interest and value if the committee would outline as far as they have gone from the standpoint of determining the forces which should be considered in designing such a slab. Of course, it is apparent that the wheel loads would serve as the reactions on such a beam. Then it would be a question of determining the distribution of soil pressures which would, from the standpoint of the structural student, be the load. If we took a lesson from the raft foundations of buildings, we might of course consider uniform distribution of the load. Many have contended that that does not take place. The question would then be,—assuming a wheel load of 11,200 pounds, over what area is that load distributed; is it a circular area; or is it distributed through an angle of 45°; or how is it distributed to determine the nature of the load? The second point would be as to the effect of impact from the standpoint of the utilisation of that highway or pavement during its serviceable life in which we must expect the concrete pavement as well as all other kinds of pavement to wear out, become rough and have certain projections which will produce impact. How much will we increase this 11,000 pounds from the standpoint of design of the structure? To 32,000 or 34,000, or what will be the increase? In the third place, what has the committee considered as a safe working stress in pounds per square inch for concrete? Presupposing we follow the example of many state highway departments and do not reinforce? If we cite the practice in structures, of course the general practice is not to accord any value to the tensile stress of concrete; but the situation with regard to structures such as bridges and buildings is entirely different because if a crack occurs it involves danger to human life. In the case of a pavement if a crack occurs it is an entirely different proposition and it is necessary to allow tensile stress to properly design it if you distribute the load to any great extent.

Mr. Goldbeck: I am not going to attempt to give the views of the committee but I can indicate the extent of our knowledge up to date in the case of pressure distribution under slabs of various kinds. Of course the pressure distribution under a concentrated wheel load, whether it be of concrete or of the non-rigid type, such as bituminous concrete, will vary considerably depending upon the subgrade conditions. Suppose you consider first a concrete slab capable of taking bending moment. Suppose that slab supported on an exceedingly soft subgrade, one almost a liquid, then a wide distribution of pressure results. If the slab rests upon a subgrade capable of very high supporting value a very high intensity directly under the load results, but not much spread. We have made a number of experiments on the distribution of pressures through slabs to subgrades of different kinds. We have used concrete slabs of different thickness and broken stone slabs of different thickness. (Illustrates by drawing.) With regard to impact we have made a number of investigations on the question using artificial impact conditions. In other words, we assumed that the truck was going to fall from different heights, those heights being governed by inequalities in the road surface, and in our tests we found that that impact is governed by a number of conditions —by the speed of the vehicle, by the tire, by the sprung and unsprung weights, by the height of fall, and I suppose by still other conditions. On the average I should say that the impact pressure to be expected under a truck wheel might be considered as being somewhere around four times the static load pressure. We have got as high as seven times the static load pressure. It might be asked what effect that has on the stress produced in the slab. Because one gets four times as much pressure that does not mean getting four times as much stress. As a matter of fact we have been making stress measurements in concrete slabs under impact and we get a considerable increase in strength as compared with that under static loads. I do not think we have gone far enough to establish what the stress is under impact as compared with what it is under static pressure.

With regard to safe working stress in tension I think the most recent work throwing light on that subject is the work now being conducted by the Illinois State Highway Commission, Purdue University, and Maryland State University. I refer to investigations on fatigue. In a concrete road you have a continuous application of loads. Machines are rolling along and you get a repeated application of loads causing fatigue. The results that have been obtained to date seem to indicate that if your stress is more than about 55 per cent of the modulus of rupture of the concrete it does not take many applications of load to cause failure.

It appears that the safe working stress in concrete should be something less than 50 per cent of the modulus of rupture. The modulus not varying from 600 pounds per square inch, the safe working stress should be something less than 300 pounds per square inch.

Dean Hughes: I take it for granted that in a great many cases underdrains do not work when they ought to work; and I suppose it is true in a majority of cases in very fine soils—the under side of the slab is cut off from the air. I should like to ask Mr. Goldbeck what his experiments show as to the intensity of pressure underneath and whether they have made any experiments using a set of air drains. I would like to ask Mr. Goldbeck what might be done if the soil underneath was air-drained, would that carry off the water? Would you expect better results than we are getting now?

Mr. Goldbeck: I should expect that with a system of drainage that would permit air to get under the slab our system of drainage would be more effective than any of our present systems. For instance, suppose we rest the road slab on a porous sub-base. I think that a porous sub-base would be effective in permitting evaporation to take place, which would not otherwise take place.

There might be other advantages in a porous subgrade in addition to providing better conditions for evaporation; that is, in effect the surface is thickened. We know, for instance, that a layer of material six inches thick will transmit a very high intensity of pressure under a concentrated wheel load. A thicker layer will transmit pressure over a wider area and greatly decrease the intensity. That is exactly what a porous subgrade would do under a concentrated wheel load.

Chairman: Will Major F. S. Besson, U. S. Army, discuss asphalt tops?

Major Besson: It is such a large subject that I hardly know where to begin. The work we have been doing in the District of Columbia has been a study of existing street pavements that have been there for periods extending back 42 years. We have arrived at the conclusion that binder course should be omitted, making, consequently, a 1½ inch surface course with the base increased to 7½ inches in order to retain a 9-inch pavement. Our conclusion is that the asphalt top does not have to be thick in order to give maximum benefit; that it is much cheaper to put money into 1½ inches of extra concrete and the 9-inch pavement will be the better for it. That points to the question which Mr. Goldbeck has just brought out; that the thickness of the concrete slab seems to affect the load-carrying capacity of the roadway to a greater extent than is ordinarily assumed to be the case.

Mr. Cummings: I would like to emphasize the point that the committee should concentrate its work on the first division and not dissipate its energy on 2, 3 and 4.

Mr. Goldbeck: I agree with Mr. Cummings that we should first outline our problems, as we are doing. We want to arrive at the best procedure in the investigation of the structural design of roads. Having done that, we are in position to outline the specific researches which are needed to carry that on.

The report was received.

Chairman: We now ask for the report of Committee Number 3 on Character and Use of Road Materials, Mr. H. S. Mattimore, Chairman.

REPORT OF COMMITTEE NUMBER 3, ON CHARACTER AND USE OF ROAD MATERIALS.

This Committee has been reorganized mainly by additions to the membership within the past several months. The object in view was to select the personnel from men actively engaged in highway research and considered specialists on the different types of highway surfacing materials.

It has not been considered within the scope of this Committee to do active research work, but rather to encourage it and investigate research problems and report on their merits. Keeping this in mind, the main activity is in the direction of cooperation with organizations concerned with the investigation and use of highway materials. Among these might be mentioned the Committee on Tests and Investigation of the American Association of State Highway Officials, the United States Bureau of Public Roads, and the laboratories or testing bureaus of some of the different states.

From a study of the research being carried on relating to highway materials in the different states and universities, as obtained by personal contact, and as tabulated in the advanced copy of Census of Highway Research Projects issued by the Advisory Board on Highway Research, it was found that an extensive field was being covered and the problems involved were quite numerous. Some of these are chiefly in the nature of experimental test work while others are of a very broad nature the solution of which would be of considerable value to all those interested in highway construction.

One difficulty encountered in our survey of investigations was the lack of standards for the sampling and testing of highway materials in general use. This condition has been recognized by the Committee of Tests and Investigations of the American Association of State Highway Officials which is a body in a position to put standards into use, and for the past several years efforts have been made to develop standard methods for sampling and testing. As a result, such methods have been secured from several sources with the expectation of having them adopted and published, in the near future, as recommended standards of the American Association of State Highway Officials. The use of these standard methods by all highway departments will make it possible to obtain comparative quality value on materials for a basis of service test study in different localities.

It was found that there was a great demand throughout the various states to have endeavor made to find methods of testing which would be predictive of the value of different materials when used in service. There is no doubt that such methods of testing are very desirable, but the inauguration of the tests must be preceded by a comparative study of different materials under traffic conditions. These studies are being made on different aggregates on highways where exact material and construction data are available.

It would be desirable to have accelerated tests of certain materials so that more of an extensive use could be made of natural local materials. In certain sections of the country this is a large problem and its solution would be an economic advance. It is known that various kinds of local material have been tried out in many different locations. A study of some structures and road surfaces where such materials have been used shows various results. It is rather difficult in such cases to judge whether a partial failure is due to the material or to a construction defect, because reliable information regarding construction methods and details is not always available. It is expected to confine these studies to highways where detailed data both as to the material used and the construction methods can be obtained.

It was thought advisable for the Committee this past year to choose two research problems for main study and to try to assemble these and analyze the existing data, arriving at some definite conclusion as soon as possible, and so the work was concentrated on the following:

First. A comparative study of concrete strengths on moulded specimens and cores drilled from the road slabs, to ascertain if moulded specimens give a reliable indication of the strength and durability of the road. It is hoped eventually to receive reports from many roads regarding their durability under traffic.

Second. Studies on toughness at different temperatures, and deformation under impact of bituminous surface mixes. The object in view in this study is to endeavor to remedy the so-called waving or pushing which has been known to occur on certain bituminous highways.

Both of these studies were carried on in cooperation with the Committee on Tests of the American Association of State Highway Officials, United States Bureau of Public Roads, and highway departments of several different states. Neither problem has advanced to the stage where any conclusion can be drawn, but enough data are available at the present time to lead to the belief that both of these studies are subjects for highway research.

Future Committee Work.

It is expected that one meeting during the year will be necessary, or at the most two. The purpose of such meetings would be to present analyzed data which had been compiled from various research problems under way, pertaining to highway materials. The Committee, as a whole, would act as a board to digest such data and give recommendations to the Advisory Board regarding the completeness of the data, of the investigation itself, or the possibility of conclusions therefrom.

The following is a list of subjects of studies and investigations which have been suggested by members of the Committee:

1. Study of sub-soil materials. Will necessitate the study of tests on different soils in order to furnish data for design of pavement.

2. A study of qualities and sizes of gravel for use in gravel roads. Would also include the amount and kind of binder necessary for an efficient gravel surface.

3. Development of some method for the recovery of a bituminous material from an aggregate or pavement in a state approaching as nearly as possible the condition in which it there exists.

4. Study of the effect of aggregates on strength and wearing quality of concrete in a road slab. To be comprehensive this should include all kinds of aggregates considered at all suitable to be used in concrete. Much data on this subject is now available, and a study of this will at least furnish information enough to judge of the value for any future work.

5. The obtaining of reliable data on the proper curing time for concrete road slabs.

6. The determining of a suitable method for ascertaining the proportion of cement in hardened concrete.

Some of the problems given for future study are somewhat interrelated with each other or with problems now under investigation; in fact it has been found in our past studies, as in all other research work, that the investigation of one problem often leads to many others which occasionally require solution before any further progress can be made on the main problem. This accounts for the fact that in many cases the solution of a main problem will take considerable time; yet the data obtained during investigation are often a valuable contribution toward present progress.

SUPPLEMENT TO REPORT OF COMMITTEE NUMBER 3, ON CHARACTER AND USE OF ROAD MATERIALS.

In determining the relative strengths of moulded specimens and cores drilled from the concrete road slabs, the Committee intends to collect the data and to study the conditions under which they were obtained by the numerous organizations carrying on this work. The following have expressed willingness to cooperate:

United States Bureau of Public Roads
New Jersey State Highway Department
Minnesota State Highway Department
Illinois State Highway Department
Maryland State Highway Department

North Carolina State Highway Department
Pennsylvania State Highway Department

Many members of the Committee believe that this is an important investigation due to the fact that the testing of specimens moulded in the field has been used as an efficient method of control of the quality of concrete being laid.

The study of subsoil materials carried on by this committee will relate to methods of routine test. They will also study the properties and identification of different materials now being used for treating subsoils or the mixing of different soils.

The work of Committee No. 2 on Design will probably be confined to the properties of soils affecting their bearing power, and a study of methods of obtaining the bearing power of soils for the purposes of design.

In the study of materials for gravel surfacing, Committee No. 3 on the Character and Use of Road Materials, will include a study of the various qualities and sizes of gravel in order to ascertain their natural binding power and the various amounts and kinds of additional binder necessary to be incorporated to make satisfactory road surfaces, as determined by laboratory tests on samples taken from known service conditions, as a guide to maintenance officials. While Committee No. 7 on Maintenance will conduct the main investigation as to the causes for corrugations and methods for eliminating them, there is a possibility that since corrugations may be caused by certain sizes of gravel or the amount or kind of binder used, it may be necessary in the investigation of gravel surfacing to make arrangements for cooperation between Committee No. 7 on Maintenance and Committee No. 3 on the Character and Use of Road Materials.

The question of the functioning of Committee No. 3 on the Character and Use of Road Materials has apparently not been fully understood, since it is apparently feared that the scope of this Committee was overlapping that of the committees of other technical societies concerned with road materials. There is absolutely no danger of such overlapping in that the Committee on the Character and Use of Road Materials of the Advisory Board on Highway Research was organized for the purpose of reviewing the foundation of research data underlying problems of highway materials, and of laying out new researches. There is no intention for this Committee, as a body, to carry on routine testing or research work proper, as it is recognized that there is a considerable amount of work now being performed by many highway organizations. The Committee will function in studying the data obtained by other organizations now actively carrying on the research, and will encourage such work. Further, there is no intention to try to standardize testing or methods of tests.

From this standpoint there is absolutely no reason for overlapping with such a Committee as D-4 of the A. S. T. M., due to the fact that the latter recommends standards for sampling and testing highway materials and necessary specifications for their use.

It is hoped to make the Committee on Character and Use of Road Materials of the Advisory Board a body which will compile and make available for distribution to those interested data on research pertaining to highway materials. Further, the Committee should investigate methods under which these research data are obtained.

The fact that the Chairman of Committee No. 3 is also Chairman of the Committee on Tests and Investigations of the American Association of State Highway Officials, is a helpful coordinating relation.

[*Note by Editor of Proceedings:*

A lengthy discussion ensued and was participated in by Messrs. Mattimore, Hubbard, Blanchard, and Johnson, concerning the possible conflict of function between Mr. Mattimore's Committee and Committee D-4 of the American Society for Testing Materials. This discussion brought out clearly the fact that Committee No. 3 of the Advisory Board was not concerned with the establishment of standards of tests or with the actual operation of investigations. As Mr. Mattimore clearly states in the supplement to report of Committee No. 3, the function of this committee, as well as that of the other committees of the Advisory Board, is to review the research foundation of technical problems and to suggest programs of research and stimulate competent research agencies to operate such programs.]

Prof. Agg: By way of comment on Mr. Mattimore's report, I should like to mention that there has recently been completed at Ames a series of investigations for determining the amount of cement in concrete after taking the concrete from a structure. The report covering this investigation and the recommended methods for analysis is now in process of printing. That is probably a step in the direction of the solution of question No. 6. In regard to the studies of concrete and foundation work in roadway surfaces, particularly dealing with the subject of durability, a study is being made on compressive strength. I did not notice any comments indicating that the committee contemplates studies of tensile strength. In all the investigations in the field of highway research, tests seem to indicate that the critical quantity for concrete is the tensile strength.

Mr. Hubbard: It appears to me that the work of Committee No. 3 will tie into the work of Committee No. 2 to a considerable extent, particularly in connection with the combinations of aggregates which will resist certain traffic conditions. I refer particularly to bituminous materials in so far as their resistance to shoving and displacement under traffic is concerned. It seems to me that laboratory research in connection with the field tests that Mr. Goldbeck's committee has under consideration will be a great aid in this work. There is considerable need for developing some tests which will indicate relative displacement under conditions very similar to traffic conditions on the actual bituminous surface. I suggest that there might be some cooperative work outlined between the two committees in that direction.

Mr. Mattimore: There are up to the present very few data on tensile strength, but a considerable amount of work is being done on modulus of rupture or transverse strength of concrete sections.

Dr. Hatt. I will call attention to the meeting in this room tonight at 8 o'clock. We are to have a paper by Dr. Raymond Dodge of the Research Council, and a discussion by Mr. William Phelps Eno of the Eno Foundation, talks by Dr. H. C. Dickinson and by Dean A. N. Johnson. The trips of inspection will be as follows: Tomorrow at 10 o'clock parties will leave from the Bureau of Public Roads, opposite the Willard Hotel, for Arlington, and for the Bureau of Standards at 1:30 in the afternoon.

Chairman: We will now pass on to the report of Committee No. 4 on Traffic Analysis, as presented by the Chairman, Mr. Geo. E. Hamlin, Special Assistant, Connecticut State Highway Commission.

Mr. Hamlin: All the work of the Committee so far has been done by correspondence, consequently the report is more or less preliminary.

REPORT OF COMMITTEE NUMBER 4, ON HIGHWAY TRAFFIC ANALYSIS.

Committee No. 4 on Highway Traffic Analysis respectfully submits the following report:

The committee appointments were accepted late in the season, so that very little beside a preliminary study of the problems involved has been accomplished. It is intended, as far as possible, to apportion the problems to the various members of the committee so that each particular subject may have the personal attention of a committee member.

Your Board has suggested eight subjects of research which may properly come under the jurisdiction of the committee.

These subjects are listed below with comments from the committee as to methods to be employed in obtaining the desired information.

1. *Report on the purpose, methods* and cost of conducting traffic surveys, the significant data to be taken, and its useful application. Many states may be aided in their plans for such surveys by a clear analysis of this field.

"It is suggested that the purpose of traffic surveys is of course, to determine the volume and character of traffic, but too frequently these traffic surveys are made only at peak periods. The method employed in Minnesota last year arranged for the state maintenance forces to carry a continuous traffic survey on the more important roads throughout the whole season, taking one or two days each week, so that the seasonable variation in traffic could be enumerated. By using men already employed as checkers or clerks on routine maintenance work, the increased expense was very small.

"Four classes of vehicles were enumerated: passenger cars, transportation lines, miscellaneous trucks and horse-drawn vehicles. In the passenger cars, a separation was made of the heavy and light passenger automobiles carrying Minnesota tags in which cars of the Dodge class and heavier were enumerated as heavy cars and all under this class as light cars. Foreign cars were also enumerated and a count of the number of passengers was taken. In the transportation lines, busses, express trucks and miscellaneous trucks were enumerated separately.

"The foregoing traffic survey was more or less superficial. Plans should be evolved which will show the character and change in volume of traffic from year to year; maps should also be prepared showing the origin and destination of various kinds of traffic from which information there can be ascertained, in a measure, the future development of traffic in a given community. I consider that the chief purpose of traffic counts is to determine where additional traffic capacity should be provided in one or more of the following ways:

(a) By widening existing roads;

(b) By constructing additional main roads;

(c) By segregating slow and fast moving traffic—as through the provision of motor truck highways;

(d) By providing by-passes around congested centers.

As the traffic to be provided for is that desiring to use the road at the busiest time of the day, the number of vehicles passing during the heaviest hour, or quarter hour, will give some indication of the need of relief; but this figure may be misleading in that a small number of vehicles may be due to relatively slow speed on account of mere numbers, or to the presence in the line of a large proportion of heavy vehicles of low speed and flexibility. A complete diagnosis cannot be made unless the census includes a record of the speed, flexibility, and degree of obstruction offered by the vehicles, while the wheel loads will afford a fair measure of the destructive character of the traffic."

Attention is called to Professor Blanchard's paper on "The Economic Value of Highway Transport Surveys," published in the proceedings of the seventh annual Michigan Conference on Highway Engineering. Also to the recommendations pertaining to the establishment in every State Highway Department of a Highway Transport Division.

At present the state of Connecticut, in connection with the Bureau of Public Roads, is engaged in a four-months traffic census covering more than fifty locations throughout the state. Three parties are now engaged in this work, two of which obtain details in regard to both passenger and truck service, type of car, number of passengers, origin, destination, mileage, pleasure or business in the case of passenger cars, and additional details as to type of commodity in regard to trucks. The third party occupies scale locations (of which there are eight) at present installed and in operation. This party obtains details in regard to trucks only, and in addition weighs both front and rear axles of each load. The results are tabulated on single cards in the case of passenger cars, and on prepared sheets in the case of trucks, and are then transmitted to Washington for tabulation.

It is hoped to continue this survey from year to year, comparing the data obtained so as to be able to plot the natural increase of travel and the necessity for additional highways which will be required because of the natural increase in highway transport.

2. *A plan for general traffic analysis* adapted to the use of states in gathering basic data of flow of traffic.

This subject is closely allied to subject No. 1. In the present census in Connecticut many of the details required last year have been eliminated, it having been found that some of the information could not be readily utilized in the analysis.

"Proposed methods of observation and analysis should be so worked out and put in such logical and simple form that they will not deter states or other political units, where funds for this sort of work are scant or where its importance is not yet fully realized, from undertaking any traffic analysis."

It is believed that a plan may be evolved which will give the basic information desired at a minimum cost and provide the comparisons necessary in different localities.

3. *A discussion of the possibilities* of the application of research to problems of handling traffic in congested situations.

4. *A discussion of "bottle neck" points* which reduce the carrying capacity of the route as a whole.

"The value of observations will be proportioned to their completeness and thoroughness, but even if they are not exhaustive they will have considerable value if the most important, even though the simplest details are gained by extensive observations. Comparisons may be made to determine the relative capacity at certain contracted points, or 'bottle necks' compared with that at other points where such conditions do not exist, provided the latter are not within the influence of the contraction, or 'bottle neck,' with which comparison is to be made."

It is expected that these two subjects will be investigated in detail by a member of the committee. Many of the Highway Departments have, during the past few years, paid a great deal of attention to the removal of the so-called "bottle neck" points and as a consequence, have increased the carrying capacity of the road, especially in those states where the roads are fast reaching their maximum capacity loading.

Typical instances of improved conditions at these points would be of value if reported to the committee for analysis.

5. *The facts gathered from surveys* relating to the effect of highways in relieving the railroads from transportation of various classes of commodities.

"Segregation of motor truck traffic, or the transportation over the highways of goods formerly handled by rail, has been referred to. In this connection it would be well to consider the other respects in which highways are relieving, or competing with railroads, viz, in the carrying of passengers by motor stages or busses. Many of the railroads serving large centers and carrying heavy long-distance passenger traffic would be glad to get rid of the commuter. This business of transportation by motor stages has assumed large proportions in California and will, doubtless, in other parts of the country. Some of these lines appear to have adopted schedules which require them to exceed considerably the speed limit fixed in state highway laws. If the time comes when special motor truck roads are provided, should these motor stages be confined to them or should they be allowed to use the roadways devoted to lighter traffic? Should not such stages and sightseeing vehicles, as well as trucks for handling goods, be restricted both as to width and weight, especially if they are allowed to use the same roadways as the pleasure or light business traffic?

This subject is one in which the railroads are vitally interested, particularly in the case of high classification shipments. The railroads are making extensive studies of this matter with the idea of eliminating the evident present competition and establishing a co-operative service of benefit to both parties. Many chambers of commerce have formed committees which are obtaining data from which it is hoped to make definite recommendations in regard to co-operation particularly in the pick-up and delivery, thus establishing a quick service between producer and consumer. Within a reasonable period this information should be available.

6. *Effect of highway transport* upon agricultural valuations.

7. *Distribution of wealth* through the state brought about through motor vehicle traffic.

"The effect of highway transportation upon agricultural valuation and the distribution of wealth brought about through motor vehicle traffic cannot be gauged at this time in the Minnesota section. So far as agricultural valuations are concerned, they have fluctuated so greatly due to other economic conditions that one would not care to make a general estimate in that respect; but it is well known that the construction of main arterial highways with surfaced feeders increases the value of land in Minnesota from $5.00 to $25.00 per acre. We also know that the development of the summer resort lake region can be almost entirely credited to the development of roads. A number of estimates have been made of the value of this development in our State but they are so widely varied that it would be difficult to say just what that might be, but it always runs into the millions of dollars."

Mr. Hamlin: Between Hartford and New Haven, a road turns northerly at an angle of 60° under an underpass, and very many accidents occurred there each year, fortunately none fatal. This dangerous point was eliminated by the purchase of a piece of property to bring the traffic to the entrance and provide a clear view through the underpass. The work was finished in time for the Yale-Harvard game three years ago, when the traffic conditions are the heaviest of any day of the year. Previous to this improvement vehicles took the pass at from 10 to 12 miles an hour. We passed the vehicles through on that day at an average speed of 30 miles. Previously, we had a backing up of traffic. At this time no particular car was held up. This is one of the best examples of a relief of traffic congestion carried out in the State of Connecticut.

In respect to loss of traffic by road transport, the situation of the New York, New Haven and Hartford Railroad is as serious as in any part of the country. A large part of the high classification shipments such as thread, machinery and brass parts, has been transferred to motor trucks. The railroad has been left with low-grade commodities such as coal, trap rock, etc.

Mr. Mattimore: In taking traffic census in anticipation of future increased traffic, how valuable will a traffic census be as a basis for new road construction?

Mr. Hamlin: In the Connecticut census there are 56 stations. Connecticut is so inter-crossed that it is almost impossible to determine which is the main route. Consequently these stations are located outside of large towns in order to determine exactly where the heavy traffic begins to lessen and the lighter traffic begins, from which information we hope to determine the type of road, width of road, and the time when heavier construction must begin. In several cases the construction of two or three miles of new road has practically changed the character of traffic.

Mr. Blair: For the purpose of studying the type and character of roads to be built, do you take into account the character of the road as related to the traffic?

Mr. Hamlin: We take that into consideration in determining both the type of pavement and location and length of construction.

Prof. Blanchard: Possibly what Mr. Mattimore mentions is a highway transport survey. The difference between the highway transport survey and the highway traffic survey is that the highway transport survey deals with future traffic whereas the highway traffic survey deals with the present traffic. The highway transport surveys are an absolute prerequisite to economic design and should consider all factors which will affect the development of future traffic on roads.

Mr. Mattimore: What I had in mind was not so much the actual number of vehicles now on a section as those sections of roads which at present are secondary roads but when actually constructed will become main roads due to some cut-off. It is difficult to determine what type or kind of road to build when that road is afterwards to become a main road.

Moved and carried that report be received and placed on file.

Chairman: We will now pass on to the report of Committee on Highway Finance, by Prof. J. G. McKay.

Prof. McKay: Due to the fact that the Committee on Highway Finance is not formally organized, the report submitted is the report of the committee chairman.

I am frank in saying that discussions of highway finance during the past few years have produced a variety of methods of raising highway revenue. The raising of public funds for highway improvement on a large scale is a modern fiscal problem. The creation of financial machinery necessary to produce highway revenue from the several sources according to principles of benefit and ability is the highway problem of today. Very little evidence is available from which we may safely draw sound conclusions to guide us in the framing of highway finance laws.

The objective of this committee is to produce the basic data necessary to the development of highway finance legislation that will produce sufficient highway revenue each year and distribute the costs of the improvement equitably between the sources of revenue.

REPORT OF COMMITTEE NUMBER 6, ON HIGHWAY FINANCE.

The successful advancement of a program of highway improvement rests upon three fundamentals: 1. Efficient highway engineering; 2. efficient highway administration; 3. sound methods of highway financing.

Fundamental and fact-finding researches have advanced more rapidly in the field of highway engineering than in any other branch of highway investigation. The valuable results of physical tests and researches have placed highway engineering upon a firm foundation.

Highway administration of the past twenty years is a record of constructive development; historically a growth from the lax, inefficient, and unscientific towards the goal of scientific and non-political highway administration. The ultimate objective is unity of control and centralization of authority—so necessary in the elimination of waste and inefficiency in the administration of the largest public improvement program in the history of the United States.

Highway financing among the states is typified by the lack of agreement in methods and in the distribution of the costs of the highway improvement between the sources of highway revenue. Neighboring states have entirely distinct systems of highway financing, and, as a whole, fundamental principles of public financing are neglected. No uniformity of principles exists *due largely to the lack of evidence upon which to build rational systems of financing.* When we consider the significance of sound methods of highway financing it is startling to find so little attention given to the problems of financing highway construction and maintenance. During the past few years a distinct opposition to the growth in the yearly highway bill has developed. *In my judgment, the current criticism of the large sums raised for the improvement of the public highway system is a criticism of the inequalities and unfairness of the present methods of financing, rather than a criticism of the amount of highway funds expended* *yearly—a questioning, not of the amount of funds raised, but of who ought to pay and how much.* The bone of contention today, tomorrow, and until answered according to principles of equity, is and will be *what percentage of the total highway revenue shall be raised from each of the sources of highway funds.* It is not so much the problem of whether a given state should make use of credit or raise funds from current revenue. The real problem is how much of the total highway bill property owners and motor-vehicle owners should contribute. The solution of this difficult problem depends largely on the results of research. The gathering together and analysis of financial data is prerequisite to the determination of the fundamental principles of highway financing.

During the past decade, and particularly during the past year, emphasis has been laid upon the use of credit in financing highway improvements—the raising of highway funds by the sale of highway bonds. I should like to sound a warning. The unrestricted use of public credit is dangerous. The past history of state debts is not a reassuring guide to the unlimited use of state credit. Let us not deceive ourselves into thinking that by borrowing funds we are tapping a new source of highway revenue. We must remember that whether highway improvements are financed by the sale of bonds or from current revenue, the same sources of revenue pay the bill in each case—the owners of property and the owners of motor vehicles.

Under certain conditions the financing of highway improvement by bond issues is justifiable. A simple test to determine the desirability of the use of credit may be stated as follows: *When the present sources of highway revenue can produce sufficient funds in any given state to carry out a reasonable program of highway improvement without unduly burdening the sources, the use of credit is unnecessary.*

While there is little agreement among the states as to methods of highway financing, two general systems prevail: (1) Financing from current revenue; (2) financing by the sale of highway bonds, supplemented by current revenue. Financing from current revenues may be divided into two types: (a) States where real property produces the major share, and motor-vehicle license the minor share, of highway funds; (b) states where motor-vehicle license produces the major share and real property the minor share of highway funds. Bond financing of highway improvement among the states and counties follows no generally accepted principles. The type of issue, bond maturity, and particularly the sources of revenue to meet bond principal and interest payments, vary from one extreme to the other. It is not the purpose of this report to enter into a discussion of the principles of highway financing. The main object is to suggest necessary researches that will aid in the determination of sound principles of highway financing. Financial research can profitably be followed along the following lines:

Research Problems in Highway Finance.

1. A survey of present methods of highway financing. Accurate knowledge of the existing state systems must be preliminary to intensive research. We must know the present methods before attempting to recommend changes.
2. A comparative analysis of highway funds raised in states using the several methods of financing highway improvements.

   This information will indicate the proportionate amounts of revenue that can be raised by different systems of financing.
3. Comparative analysis of highway expenditures and the sources of highway funds in typical states to determine the share of the total highway improvement costs each contributing share produces.

   This information is necessary to show what part of the costs each source of revenue bears.
4. *Analysis of the share of the total highway improvement costs each contributing source of revenue should produce, based on the benefit and ability theories of taxation.*
5. Surveys of the contribution of urban and rural sources of highway revenue.

   Data of this type are necessary to determine whether or not it is necessary to differentiate between urban and rural taxation for the purpose of rural highway improvement.
6. Research in highway bond financing.
   - (a) The total highway bond indebtedness—state and county.
     - (1) The types of issues.
     - (2) Maturity, rates of interest, and marketing factors.
     - (3) Methods of amortization.
   - (b) General principles determining the necessity for the use of credit.
   - (c) The distribution of the cost of bonding, principal and interest, between the sources of highway revenue.
   - (d) The cost of different types of highway bond issues according to maturity and amortization.
7. The amount of personal property taxation of motor vehicles.

8. Analysis of the relative merits of present methods of motor-vehicle taxation.
9. The relative benefit to vehicle transportation of the different types of highway improvement.

   These data are usable as one of the measures of motor-vehicle contribution to highway improvements.
10. The average benefit to rural land per acre due to highway improvements. Will serve as a rough measure of real property taxation for rural highway improvements.

Chairman: Some of the state highway commissions are establishing very fine records of efficient highway engineering. The costs for engineering compare very favorably in my judgment with those incurred in other public undertakings. The percentage for overhead for very efficient highway work was approximately five per cent, which included all the accounting, and the accounts were kept so completely that complete records for the entire state were filed with the Governor within thirty days of the close of the calendar year. The quality of work in many states contrasts very favorably with the work done in many of the cities.

Prof. Blanchard: I trust that it will be practicable for this committee to disseminate certain information which is very much needed at the present time, because there is such a confusion of ideas, on the part of owners of real estate especially, as to the benefits derived from the improvement of highways to which Dr. McKay has referred. The tendency in Michigan is to follow in the footsteps of the states of the middle west, putting the entire burden on the motor vehicle; but we are now discussing the fundamental principles involved in shifting the burden of revenue obtained from rural road estate to the motor vehicle in the form of a 2-cent gasoline tax. We find a lack of knowledge in regard to benefits to be derived. The day before yesterday Mr. Roy D. Chapin enunciated some of these fundamental principles and by means of his talk changed the views of perhaps twenty-five members of the state legislature who had no conception of some of the fundamental principles which Dr. McKay has brought forth this afternoon.

Chairman: In the state of Iowa, the total tax burden last year was $110,000,000; the school burden made up about one-half of that, about $55,000,000; the amount actually collected by taxation for road purposes was about $15,000,000 and from automobile license receipts $7,500,000, making a total collection of $22,500,000. The state spent about $38,000,000 for work on its highways. This includes all lines, including county and state work. The difference was due partly to accumulations of funds, partly to issuance of bonds, and partly to special assessments. The taxpayers are very much disturbed over the burdens in our state, yet the average taxpayer pays a comparatively small amount for highways. The highways constitute, after all, a very small percentage of the total tax burden, not more than one-fifth in our state, so that the elimination of all taxes for highway purposes would still leave the farmers kicking about as hard as they do now. However, we are trying to reduce these expenditures. The bulk of the expenditure was directly under the state highway commission and the counties.

Mr. Blair: The highways are the only public institution now left for the benefit of all. Therefore, I think a uniform rule of taxation ought to be employed for road building, for it benefits the city man the same as it does the country man. Sometimes we are too apt to collect taxes for road building through the avenue of least resistance. They are levied here and there on this and that from whatever source can be reached. I have no interest at all in the manufacture of, but I have an interest in the use of automobiles. We ought to take warning against the cry now prevalent all over this country to assess an unequal amount of money against the automobiles and motor trucks.

The report of the Committee on Highway Finance was received.

REPORT OF COMMITTEE NUMBER 7, ON MAINTENANCE OF ROADS.

The Committee on Maintenance of Roads is not yet fully organized. In fact acceptances have not yet been received from all of those who have been invited to become members. The chairman therefore submits the following report more as a basis for future work than as a report of present accomplishments.

The Advisory Board's census of highway research projects shows nine distinct subjects which are being studied by fifteen separate organizations. There are no doubt other important research works which are not included in the census. The following table shows the problems which are now being investigated:

A. Concrete pavement
    1. Crack fillers
B. Gravel roads
    1. Dust preventives
    2. Bituminous wearing surfaces
    3. Rhythmic corrugations
    4. Maintenance machinery

C. Earth roads
  1. Oiling
D. Snow removal
E. Traffic guides

All research bodies working on the foregoing projects have been corresponded with and progress or final reports secured whenever possible. The status of the work with a brief summary of the conclusions drawn by the investigating parties follows:

A-1. *Concrete Pavement Crack Fillers.* The United States Bureau of Public Roads has made an investigation to develop a concrete pavement crack filler having the same color as concrete. Mr. L. G. Carmick, chemist for the Bureau, has made a report of this work which is dated August 1, 1922. It appears that after an exhaustive search, a satisfactory substance has been found. However, the conclusion is not altogether certain. A more extensive practical experiment will be started in the near future. The product which seems to be satisfactory is described in the report: "The substance referred to is a compound of rubber, petroleum oil and pine rosin combined with a mineral filler. Crude, unvulcanized rubber is cut with about twice its weight of kerosene or light lubricating oil. This is added to melted rosin and thoroughly incorporated with it. The best proportion between rubber and rosin is not yet settled. Probably this will depend upon the climate in which the material is to be used, for the compound should be neither too soft in summer nor too brittle in winter. In the vicinity of Washington one part of rubber to twelve parts of rosin appears to be about right."

Quoting further from the report: "This crack filler can be manufactured at the present time at a cost that should not exceed ten cents a pound. It can be shipped in barrels or other containers as easily as asphalt can. It is melted at the roadside in open kettles and poured into the cracks. No delay of traffic is necessary, as it hardens immediately. While the cost is undoubtedly greater than for asphalt, it is, after all, but a small item in the cost of a concrete road, and the greatly improved appearance due to the absence of unsightly black streaks would justify the slightly higher price."

Cornell University has also made a study of crack fillers for concrete pavement, but their report is not available.

B-1. *Gravel Road Dust Prevention.* B-2. *Gravel Road Wearing Surfaces.* Studies of dust prevention and wearing surfaces on gravel roads interlock closely, as all suitable wearing surfaces also act as dust preventives. The University of Michigan and the Michigan State Highway Department have just completed extensive research work with various bituminous surfaces and dust preventives for gravel roads. Their final report is being published. The work was done by G. C. Dillman, Deputy Commissioner of the Michigan State Highway Department, and Herschel C. Smith, Assistant Professor of Highway Engineering, University of Michigan, under the direction of Prof. A. H. Blanchard. Their preliminary report shows that experiments were conducted on three test roads having a total length of about eighteen miles. Roads were chosen which carried a traffic of from 500 to 2,500 vehicles per day and which had from ¼ to 1½ inches of loose material on the surface. The test sections were one-half mile in length, and the following materials were used:

High carbon tar, ¼ gallon per square yard.
Special refined tar, light grade, ¼ gallon per square yard.
Special refined tar, light grade, ⅛ gallon per square yard.
Light oil, ⅛ gallon per square yard.
Heavy oil, ⅛ gallon per square yard.
Cut back oil, ¼ gallon per square yard.
Cut back asphalt, ¼ gallon per square yard.
Flake calcium chloride.
Granular calcium chloride.

The preliminary report shows the following conclusions:

"1. Any surface treatment of gravel roads for dust prevention should extend the full width of the traveled way rather than over a portion of the center of the road, such as 16 feet.

"2. For general use as a dust palliative on Michigan gravel roads, calcium chloride is the most satisfactory from the point of view of general practicability, application by unskilled labor and adaptability to various types and conditions of road. It is impossible, from data based upon these service tests of but one season, to reach conclusions as to its effectiveness and economy compared with other dust palliatives investigated.

"3. No distinction can be made between granular and flake calcium chloride as to effectiveness.

"4. Calcium chloride supplied in the 100-pound bag containers is more economically handled than that supplied in the 350-pound metal drum and it appears that it might be profitable to provide the necessary storage so that this economy could be realized.

"5. The use of calcium chloride has a tendency to cause the surface to pit and become rough, which slightly increases the cost of blade maintenance above that of a similar road on which calcium chloride is not used.

"6. It appears that a light oil such as that applied on Section E can be used on a gravel road even under a traffic of 1,500 vehicles per day, in case there is a sufficient amount of loose material on the surface to absorb at least 75 per cent of the oil.

"7. Where the light oil as applied on Section E is applied in a greater quantity than that which the loose material will absorb, it forms a thin glazed surface on the compacted portion of the road and the loose material which is quickly swept from the road cannot be successfully replaced, as there is no tendency for material returned to the surface to adhere and become incorporated in the surface.

"8. It is impossible, as yet, to standardize the use of light oil as a dust palliative for Michigan gravel roads because of the necessarily exact relation that should exist between the amount of oil applied and the amount of loose material. In no case should more than one-eighth gallon per square yard be applied and the amount should vary with the amount of loose material on the surface.

"9. The heavier bituminous materials used—such as were applied on Sections A, C, D, F, G, and H—cannot be used for a dust preventive on Michigan gravel roads except as a material for forming a bituminous surface.

Bituminous Surfaces.

"10. Regardless of the material used, a successful bituminous surface cannot be formed on a gravel road unless there is first on the gravel road a firm, even, hard surface free from loose material.

"11. Bituminous surfaces formed within the limits of conclusion Number 10 and with the materials and amounts used in these tests do not disappear uniformly.

"12. It appears that bituminous treatments made without top dressing and expected to disappear annually, although apparently satisfactory during the summer months when used on a high-type gravel surface, will leave the road in such shape that succeeding treatments will be impractical unless the roadway surface is reconstructed, and furthermore will impair the quality of the surface if it is to be maintained thereafter as an untreated gravel road.

"13. It appears that it would be possible, however, to develop a bituminous surface, using a suitable metal top-dressing on firm, even, hard, well-cemented gravel roads, of which there are relatively few miles in this state."

The Wisconsin State Highway Commission has also carried on some experiments on surface treatment of gravel roads. Their report will be available after January 1.

The Pennsylvania State College issued in 1915 a report of an investigation of dust prevention. They experimented with:

- Water sprinkling
- Sprinkling with sea water
- Calcium chloride treatment
- Waste sulphite liquor
- Vegetable and animal oils
- Road oils
- Emulsions
- Tars

The following conclusions were drawn: "Earth roads will usually best respond to treatment with water, calcium chloride, and light oils. Gravel and macadamized roads may be treated with these or with asphalts, emulsions of oils, and tars. Very sandy roads will be improved if a suitable amount of clay is first mixed with the sand and the whole consolidated before the application of a dust preventive. In like manner a very clayey road should be given a suitable admixture of sand to produce a better stability before the surface treatment."

B-3. *Rhythmic Corrugations in Gravel Roads.* The most extensive research work in connection with this very perplexing problem has been done by the United States Bureau of Public Roads. George E. Ladd, Economic Geologist for the Bureau, has written a report covering their investigations. Studies were made in Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New Jersey, Michigan and Wisconsin, It was found that the distance from crest to crest averages about 31 inches and that the maximum height from the bottom of the trough to the top of the crest is 1½ inches. The causes of the corrugations are:

1. The kick-back of surface materials arising from the spin of the rear wheels of automobiles as they descend after a bounce over some obstacle or depression.
2. From impact of both the front and the rear wheels of automobiles.

This class of corrugation is more prevalent when the clay content of the gravel is high and especially where the gravel particles are well rounded. In the case of the first-named corrugations, the location of the corrugations remain fixed. In the case of the second class, they seem to swing on an axis located near the center of the road. In some cases the swinging movement was so great that corrugations which were originally at right angles to the road took a position only a few degrees from the axis of the road. "Gravel roads subject to a traffic of not more than 200 or 300 cars per day remain practically free from corrugations, if occasionally dragged. As soon, however, as traffic reaches 400 or 500 cars per day corrugations develop very rapidly." Quoting further from the report: "The fact that these corrugations are so general and occur in all sections of the United States makes it evident that nearly all gravel roads are subject to the development of this nuisance and menace, if they serve sufficient traffic, although the methods of construction and kinds of gravel vary widely. The situation, however, is not hopeless. Several highway officials have expressed the opinion that less corrugation trouble is found where the gravel is angular than where it is composed of highly rounded particles. It is also claimed that where the road is constructed of gravel more uniform in size than pit run, and especially where everything over one inch is excluded, corrugations are slower in developing and more easily eliminated by maintenance methods." * * * "During the writer's investigations in the state of Maine it was noted that roads with a relatively high per cent of clay-silt binder were comparatively free from corrugations."

The report concludes: "This problem remains for future solution and must be worked out by a combination of field observations and laboratory tests. In this connection it may be stated that the present standard tests of gravel are unsatisfactory in that they do not include determination of the nature and qualities of natural binder originally in the gravel. The so-called cementing value test has to do only with the products of abrasion of individual gravel particles. While it is important to determine this factor, there must also be, in addition to the facts brought out by mechanical analyses as to the quantity of clay-silt binder, a determination of the cementing value of this fine material. The writer is now engaged in experiments connected with the testing of different mixtures of gravel, sand and clay-silt binders, and their behavior under different degrees of compacting and with different amounts of water present. In future investigations observations must be made over a wide area and under varying conditions as to the relation between the amount and kind of natural binder in the road and the behavior of the road under traffic. Another interesting problem in this connection is the question of migration of clay binders toward the surface, and their ultimate loss to the road through the combination of rain, wind and traffic influences."

The Vermont State Highway Commission have attacked the problem of rhythmic corrugations but have not issued a formal report. Commissioner Dix, however, in a letter states that corrugations in his state are confined almost entirely to flats and straight-of-ways and appear to be formed by high-speed vehicles. The presence of moisture greatly contributes to the formation of corrugations. A small per cent of clay also helps for the reason that it retains the moisture. He believes that a traffic of 400 to 500 vehicles per day will cause corrugations unless the road is treated with calcium chloride or tar.

B-4. *Gravel Road Maintenance Machinery.* The Idaho Department of Public Works have designed a sand distributor for gravel maintenance. The sand distributor is an attachment for the standard gravel dump-body truck. It consists of a roller, covered spirally with heavy rubber belting which is driven by means of a sliding gear from the rear end of the truck transmission and operated from the driver's seat by means of a lever.

C-1. *Earth Road Oiling.* The University of Illinois has carried on an earth road oiling experiment in Champaign County, Illinois. The work has been under the direction of Prof. W. M. Wilson. His report is not yet ready for publication. The experimental road was 12.3 miles long and had been graded in an excellent manner. The oil sections were on an average 1,200 feet long and four distinctly different types of oil from six refineries were used. From one-fourth to one gallon per square yard was applied.

The Illinois Department of Public Works has also carried on an oiling experiment on earth roads in Sangamon County. No data are available at this time. It is probable that a bulletin will be published during the winter.

D. *Snow Removal.* The Wyoming State Highway Department have for several years experimented with elevated grade lines to eliminate snow hazards. They have followed out this principle on about 2,000 miles of construction. Their state highway engineer, Mr. Z. E. Sevison, says: "It is our practice to lay the grade line 12 to 18 inches above the natural surface of the contiguous ground. The cuts are eliminated except in cases where it is unavoidable in order to secure satisfactory grade. We do not hesitate to deviate from tangents or section lines in order to secure the proper location on account of snow conditions.

"This has practically eliminated the snow hazard on all of our constructed projects. There is no question in my mind but what this is the proper construction in a windy country subject to drifted snow. There would probably be nothing gained by adopting this plan in those sections where there is very little wind to sweep the snow off the surface of the road."

E. *Traffic Guides.* The subject of traffic guides for highway traffic regulation has been thoroughly investigated and is fully covered by

Mr. Eno's "The Science of Traffic Highway Regulation." Mr. Eno, however, has confined his investigations to city traffic. There is great need for research work leading to standardization of highway traffic signals on rural roads.

A special committee of the Mississippi Valley Association of State Highway Officials and the Maintenance Committee of the American Association of State Highway Officials are both studying the matter of rural traffic signals, and preliminary reports will undoubtedly be available this winter.

Recommendations. The chairman of the Maintenance Committee recommends (without having had opportunity to consult the other members of the committee) that in addition to completing the researches already started, as outlined in this report, special research work be undertaken to develop the most feasible uniform system of maintenance accounting, so that maintenance reports of various states may be put on a more comparable basis.

The report was received.

Evening Session.

The meeting was called to order at 8 o'clock by the Chairman, who introduced Mr. Thos. H. MacDonald, Chief of the Bureau of Public Roads.

Mr. MacDonald: We are delighted with the interest which has been manifested in research work. We have believed all along that the development of a proper system of highways for this country is dependent upon education and research more even than upon the actual appropriations made. We might for a time carry on with appropriations, but unless we can go forward with our educational and research work, I do not believe we can secure the public support necessary. I have had this year the opportunity to study roads in the most undeveloped sections of our country. A number of things have brought home to me the size of the program we are undertaking. We find the Pennsylvania Railroad advertising the completion of a roadbed from Chicago to New York over which trains can be operated safely in twenty-four hours, a distance of 900 miles. We have the job of building highways across distances similar to those covered by this railroad, and of carrying traffic safely with rolling stock amounting to over ten million vehicles in separate units.

So far as the Bureau is concerned, we believe that the money we are spending for research, in view of the tremendous size of the job which we are undertaking in this country, is the money best spent.

Dr. Raymond Dodge, chairman of the Division of Psychology, National Research Council, then presented a paper.

THE HUMAN FACTOR IN HIGHWAY REGULATION AND SAFETY

By RAYMOND DODGE, *Chairman, Division of Anthropology and Psychology, National Research Council*

Problems of the maximum usefulness and the maximum safety of highways are of two main varieties. One variety, of necessity the first and one most commonly considered, concerns the speed, direction, frequency, and weight of traffic and the reactions of the road. The other concerns the human factor, human perceptions and reactions, human attention, frailties and confusion. The first variety of problems is physical. The second is mental or psychological.

Notwithstanding some exceedingly valuable special investigations, especially by Mr. Eno and the Eno Foundation, as far as I am aware, no systematic exploration of the human factor in traffic has ever been undertaken. For obvious reasons it is more difficult than the physical factor. With increasing congestion of traffic it is certainly not less important. Many otherwise useful schemes have suffered from a lack of insight into the mental processes which they involve. At the beginning I wish to disclaim any special wisdom in the matter of the psychology of the highway. It needs careful analysis and expert, thoroughgoing, experimental investigation. It is my present purpose merely to emphasize the importance of studying the human factor and to illustrate my points by fragments of problems that have appeared to me in casual observation. Mental problems of the highway seem to me to include the following classes:

1. The nature and placement of signs.
2. The nature and time of signals.
3. The visual limitations of drivers and pedestrians.
4. Limitations of attention and sources of confusion of drivers and pedestrians.
5. Minimum reaction times consistent with safety. Reaction time and physical momentum bear direct relation to the permissible speeds.
6. The development of standard tests and the correlation of tests with the various sorts of licenses to operate at different speeds and in different localities.
7. Education for safety.

If I may be permitted to call attention to some specific cases of inadequacies that have come to my attention, I can perhaps illustrate some of these points better by concrete instances than by generalities.

1. Concerning Signs.

In front of the offices of the National Research Council there stands a sign with "SLO" on the top line and "SCHOOL" on the bottom line. I do not know the theory under which that "SLO" was designed. There is an obvious effort to dodge the adjective slow, and an equally obvious belief that words are read letter by letter, that a strange word of three letters is more quickly read and grasped than a familiar word of four letters. With the grammatical issue I shall not quarrel, although *slow* as an abbreviation for "slow down" or "slow up" would be reasonably good English. The real objections to "SLO" come from the known facts in the psychology of reading. It has been thoroughly demonstrated that adults do not read familiar words letter by letter but by familiar letter groups. Any combination of letters may become familiar in time. New combinations are read and understood relatively slowly. When I first saw that strange sign it took me many times the effort and time to understand and interpret it that would have been sufficient for "slow." For the average stranger in Washington to whom that sign should especially appeal the familiar group of letters—slow—would be read and understood in a fraction of the time that was necessary for the interesting and ingenious configuration. This is a trival case. There is, however, a very real and important problem with respect to the ideal construction of a traffic sign. How many words will be read in the available time by a passing autoist? What should be the minimum size of letters? Where should signs be placed so that they will get the best attention of drivers or pedestrians? Uniformity in structure, placement, color, and content is a real desideratum. There is already available a body of practical experience and a considerable body of scientific information which would only need to be adapted to highway use and experimentally verified.

Another case that fell under my notice was the effort to increase visibility of the trolley posts on Connecticut Avenue by painting long white bands on them. By an unfortunate accident these bands began several feet above the ground. The optical usefulness of the white bands would have been enormously increased if they had run to the ground. Then the position of the posts in lines of perspective would have much more clearly defined their spatial position. More fundamentally, which is better, white posts or alternating bands of black and white?

Again I have noted the relative lack of visibility in the growing dusk of traffic policemen in their dark uniforms with dark gloves. The addition of a diagonal white sash and light gloves would enormously increase their usefulness to pedestrians and their visibility to drivers.

2. The Nature and Time of Signals.

As far as I can learn Washington has at least tentatively adopted hand and arm signals considerably ahead of the country at large. It is, however, conspicuous that these signals have no definite time relation to the movements they indicate. They are sometimes short and sometimes long, sometimes early and sometimes late. It seems particularly unfortunate that at a time when both hands of the driver might be needed for the operation of his steering device and emergency brake he is supposed to be using one of those hands for signaling a stop. Some one of these processes is likely to be poorly executed. The continuous indication of a driver's intentions beginning at least five seconds before a movement is executed and continuing until a movement is completed would be a great advantage. It is mechanically entirely possible without interrupting the driver's control of the machine, if we settle the principle. Similar indications by pedestrains, at least in crowded places, would be a great help to the drivers and should be enforceable. It is often quite impossible for a driver to determine when a pedestrian is going to start a movement across the street, when he is going to retreat, or what direction he is going to take next. A simple scheme for the most desirable time of onset and the duration of signals can be worked out by any psychologist who will familiarize himself with the traffic situation, and who knows the limitations of attention and reaction time.

3. Visual Limitations.

Perhaps the most obvious psychological service would be rendered in connection with the limitations of attention and the extent of clear vision. In the present regulations of traffic the active concern of both driver and pedestrian never covers less than forty-five degrees of visual angle and may reach an angle of two hundred degrees and over. The upper range is humanly impossible without moving the head from side to side. This always involves the interruption of vision in some part of the field of active concern. One of the greatest dangers in crossing the street comes from vehicles that suddenly emerge unseen and unheralded from a side street. Means for decreasing the visual angle of active concern should be carefully scrutinized and adopted wherever possible. The prohibition of all left-hand turns is an expedient for which a splendid brief might be prepared. Another brief might be prepared for the use of all parallel streets as one-way traffic streets. Safety, maximum speed, maximum parking facilities, and saving of time with consequent relief of congestion and the convenience of foot traffic are all involved in one-way streets. Similar advantages are obtained by dividing wide streets by zones of safety wherever practicable.

On the grounds of the visual angle of active concern there is a slight but real difference between different sides of the street for pedestrians. It can be demonstrated that the left-hand sidewalk is safer. It is well-known that the left-hand side of the street should be used by pedestrians when there is no sidewalk.

As a matter of safety there are grave doubts as to whether the present regulations that limit pedestrians to a narrow street crossing at exact intersections of streets is the best practicable solution. It may be more convenient for drivers but the exact intersection of streets is certainly most dangerous for pedestrians. Behind waiting cars is safer than in front of them. Twenty feet from a cross street would diminish the probability of being surprised by turning cars.

4. Sources of Confusion.

Much has been done to diminish the sources of confusion, such as the introduction of signals and the establishment of zones or islands of safety where pedestrians can take their problems in smaller doses. But, if I am correctly informed, any systematic analysis of confusion of pedestrians or drivers has yet to be made. It would involve the practical limits of attention and the facts of human variability. The sudden appearance of an unheralded vehicle coming around the corner, the convergence of vehicles on the pedestrian and even the blatant automobile horns themselves are worth considering as sources of confusion. In this connection one may note again the advantages that would be derived from one-way traffic. Confusion would be diminished by uniformity of traffic rules and signals, by training in time and space estimation, by better lighting of cars, and a better system of street lighting. Most street lighting involves decrease of the visual acuity by peripheral glare.

5. Minimum Reaction Times.

Aside from the purely mechanical conditions of stopping and turning the next most important factor in safety is the reaction time or personal equation, the time that elapses before the driver or pedestrian can start a movement that is required by a sudden emergency. Slow and uncertain or wavering reactions are undoubtedly the occasion of many accidents. Long reaction time is partly due to natural tendencies of drivers and pedestrians—the so-called personal equation. It is also due in part to lack of practice and training in appropriate reactions. Both of these factors could be made matters of test.

6. Standardized Tests.

An even more conspicuously opportune field for psychological co-operation in solving the problems of safety and efficiency on the highway is the matter of constructing and evaluating a series of standardized tests for drivers. It is possible that there ought to be tests for pedestrians as well, with distinguishing marks for incompetents. It would be some help if the drivers could know that the man trying to cross the street was partially paralyzed, was partially blind or deaf, had a wooden leg, or some other disability which made it difficult to take care of what he had left. As it is now youth and old age are the only clearly marked incompetents.

It is notorious that tests of drivers in one community are entirely different from tests in other communities. Licenses from different localities are quite incomparable in value. Standard tests would be a real help. But standardization of tests is not the only service that can be rendered. It is entirely thinkable that tests should vary for the sorts of tasks which the drivers are called upon to perform. That is to say, tests for drivers of light pleasure vehicles might conceivably be very different from tests for drivers of fast ambulances, or fire appliances; and they in turn might be quite different from tests for drivers of heavy motor trucks. High-powered fast machines obviously should not be entrusted to poor or relatively untrained drivers. A specific form of test for various types of machines is good common sense and good science. In addition to tests for mechanical expertness it is probable that tests for drivers of motor vehicles should be supplemented by tests of knowledge of standardized traffic regulations and automobile limitations, and possibly by some check on moral tendencies and regard for common interests. The preparation and standardization of a series of tests for drivers would be a task of no small magnitude and of conspicuous importance. Forfeiting a license for misconduct on the road should be a national affair, not a merely local one. Driving after license is withdrawn should be a serious offense.

7. Education for Safety.

In addition to all of these possible services of psychology in the regulation of the highway there is undoubtedly need of the service of expert educationists. The pedestrian must be trained as well as the driver of motor vehicles and the proper place for that training is in the school. It seems reasonable to suppose that one of the important school functions in fitting the child for his environment is the ability to take care of himself on the highway. This task obviously can be undertaken only when the regulation of the highways has reached a point where it is uniform in all the states and uniformity should only be aimed at when we are sure that from the standpoint of space and time as well as from the standpoint of the human mind the proposed regulations have been thoroughly scrutinized and revised. Newspaper and movie campaigns by cartoons, advice, and stories should be continuous, not limited to one week a year.

STATEMENTS FROM REPRESENTATIVES OF CONSTITUENT ORGANIZATIONS

Prof. W. A. Slater, representing the U. S. Bureau of Standards: The Bureau of Standards is anxious to be of service to the Advisory Board on Highway Research and to the work of building adequate highways. It may be of interest to mention some of the current and completed work which has to do with the subjects under discussion today. The first, which needs only to be mentioned because you will hear more of it from Mr. James this evening, is the subject of automotive engineering.

An experimental investigation of power losses in automobile tires is being made. It was found for example, that more mechanical energy was absorbed in fibre tires than in cord tires. Technical Paper No. 213, of the Bureau of Standards, gives some results of the investigation. Endurance tests of tires are now in progress, day and night, in which comparative data for tires of different types are being obtained. Specifications for automobile tires, both pneumatic and solid, have been prepared at the Bureau of Standards. These specifications have been adopted by the Federal Specifications Board for the purchase of government materials and have been published as Circular No. 115 of the Bureau of Standards.

The subject of bituminous coatings suitable for retaining-walls, bridges, etc., has received some study and the Bureau of Standards has on hand unpublished data which should have value in the selection of a coating which requires sufficient elasticity to span cracks of pre-determined width and retain sufficient solidity so as not to run during warm weather.

Soil pressures have been studied by the Bureau of Standards and a report was made which was published in the Proceedings of the

American Society of Civil Engineers for August, 1920, as a part of the report of the Committee to Codify Present Practice for Bearing Value of Soils for Foundations. The work has been interrupted at the present time, but fundamental data have been obtained. Equipment is on hand at the Bureau of Standards, and it is lack of funds only and not lack of interest that has interrupted the work. No definite plans are being made for further work, and it is largely a matter of interest from the outside as to whether this work will be continued.

Some general problems in concrete are under investigation. I might mention as one of them the measure of workability or consistency of concrete and the effect of admixtures of various kinds on the workability or consistency. The subject of expansion and contraction of concrete has also been investigated. The variation in proportions and strength of concrete due to the varying amounts of sand and moisture when sand is measured by the ordinary methods by volume, is a source of trouble in making concrete. We have completed a very interesting investigation which aims at correcting this trouble by measuring the sand in water. A paper giving the results will be presented at the January meeting of the American Concrete Institute. We have found also a satisfactory uniformity in the strength of the resulting concrete when by this means the same quantity of material is put into the concrete each time.

Reinforced concrete is under investigation, although no tests are now in progress. A paper on tests of concrete slabs reinforced with expanded metal and other types of slab reinforcement is now in press. We believe we have analyzed some of the laws of strains and stresses in reinforcement which has a diamond mesh instead of bars extending in one direction.

Some study has been made of the form of standard test specimens for the determination of bond resistance between concrete and steel.

Mr. W. S. James, of the U. S. Bureau of Standards: The work of the Bureau of Standards was started primarily from the viewpoint of the automotive engineer, and was originally intended to shed some light on the difference in fuel consumption due to change in the design of the intake system. It was felt necessary to obtain the results in such form as to have the most carrying power to the people in the country, and so it was planned to experiment with vehicles in operation on roads. We have designed and constructed apparatus that will record the entire performance of the engine and vehicle on the road. In designing this apparatus, the following factors were taken into consideration:

1. Energy input.
2. Energy output.
3. Conditions under which the energy was transformed from mechanical energy into mechanical thrust.

The apparatus was autographic, and designed so as to be adaptable to any car. Photographic methods were eliminated as far as possible, in order to observe the records while they were being taken. The fuel flow measurement is made with a flow meter. To assure the power output, the accelerometer method is used. In order to use the accelerometer to measure power intake, it is necessary to measure the actual acceleration either linear or against gravity, and second, to measure rolling resistance, wind resistance and various friction losses in the car. The sum of these two measurements gives the total effective thrust of the car. In measuring the rolling resistances of the vehicles, the roughness of the road enters to quite a material extent, and we have had some indications of possible methods of measuring road roughness by means of an accelerometer.

Mr. Wm. P. Eno, representing the Eno Foundation: Standardization of General Highway Traffic Regulations is the most important step for the immediate future. By General Highway Traffic Regulations I mean those regulations which are all-sufficient for the greatest city and contain nothing superfluous for the smallest village. Fortunately we have such a set of general regulations ready for universal adoption. These general regulations have passed through numerous revisions since their first official adoption in New York on October 30, 1903. They are now known as the Council of National Defense Code of General Highway Traffic Regulations.

The question of Special Regulations is another matter. Special Regulations need not be printed but should be indicated on the spot by traffic guides and be under police supervision, guidance and control.

The time has come at last when we must realise that traffic regulations planning should be done by those mentally fitted through scientific training. The police work in traffic regulation should be confined to supervision, guidance, control and enforcement when necessary.

I feel that meetings such as this, and others I have attended lately, are most encouraging. It means that we shall not be so much alone in a work which deserves the best efforts of the best minds in the country; for surely there is no other subject more important to the world than "the regulation of the movement of vehicles and pedestrians so that they interfere with one another as little as possible and are enabled to go from point to point in the shortest time compatible with safety.

Mr. D. C. Fenner, representing Mr. A. J. Brosseau for the National Automobile Chamber of Commerce: Work of late has been largely for a better understanding between those who make and operate vehicles on the road and those who are charged with the enforcement of the existing laws controlling mainly the weight and size of vehicles. The work has received considerable impetus of late on account of a request from the motor vehicle department in the State of Connecticut for some practical form of yardstick or formula which might be used for quickly gaging the capacity not only of the well-known makes of vehicles which are now on the market, but for the home-made vehicles—those which are resurrected from the different junk dealers in the community and put together without any great regard for their braking or steering ability, vehicles which are a distinct menace to public safety. They hold up traffic on the road and cause undue road damage. While we found it impossible actually to produce the yardstick or the formula, we are now in a fair way to furnish the enforcement officers with some of the information which they require. Data on maximum allowable load upon both front and rear axles are being obtained, as well as maximum speed and distance required to stop a vehicle traveling at that speed with either set of brakes operated independently.

Prof. A. H. Blanchard, representing the National Highway Traffic Association: The National Highway Traffic Association is endeavoring, through the medium of its annual meeting and annual convention, the meeting of its five divisional organizations—North Atlantic, South Atlantic, North Central, South Central, and Western Divisions, and about forty National Committees, each composed of from three to twenty-five specialists, to formulate basic principles and to promote the efficiency and regulation of highway traffic and highway transport. In order to give some idea of the research work of the Association, the titles of some of its chief National Committees are noted as follows: Equitable Distribution of the Cost of Construction and Maintenance of State Highways; Status of the Construction of Highway Curves and Recommended Practice to Increase Safety of Traffic; Traffic Center Lines on Roadway; Relative Efficiency of Different Types of Car Stop Safety Zones and Their Relation to Parking and Ranking Regulations; Segregated Traffic Streets in Municipalities; Widths of Roadways and Sidewalks in Municipalities; Traffic Capacity and Widths of Highways Outside of Municipalities; Traffic Control; Uniform Highway Signs; Uniform Municipal Traffic Regulations; Safety Regulations at Railroad Grade Crossings; Interrelationship of Highway, Railway and Waterway Transport; The Railroad as an Operator of Highway Transport; Regulations Covering Speeds, Weights and Dimensions of Motor Trucks and Trailers; Regulation of Overloading of Motor Trucks; License Fees and Motor Vehicle Taxation; Lights for Highway Vehicles, Motor-Driven and Horse-Drawn; Economics of Highway Transport; Highway Transport Franchises; Highway Transport Clearing Houses; Store Door Delivery; Motor Bus Service for Consolidated Rural Schools.

Dean Anson Marston, representing the Association of Land Grant Colleges: The Association of Land Grant Colleges has not yet selected its official representative on the Advisory Board. One of these institutions is located in each state, and all were established by Act of Congress in 1862. Each institution has funds appropriated by the individual state, supplemented from federal sources. The engineering section of the Land Grant Association has been promoting engineering research in these institutions, and has had the support of the general Association of Land Grand Colleges which now maintains a standing committee on "Engineering Experiment Stations." Dean C. R. Jones of the University of West Virginia, is secretary of the section, and secretary of the standing committee. The committee collects statistics of engineering research at the Land Grant Colleges in the various states, and publishes the same, quarterly. The statistics collected and reported at the meeting which has been held in Washington this week, show that the sum of $475,000 was spent in engineering research at Land Grant Colleges during the past year. Eighty-four men at such colleges are devoting full time to research; 66 devote part time and are paid for their work; and more than 300 men devote some time to research, but without pay. These institutions owe special obligations to the country and to their states; their mission is to foster both engineering education and engineering research. A number of institutions are engaged in highway research work, some in cooperation with the highway organizations, and some in cooperation with the Federal Bureau of Public Roads. I may speak of Iowa State College with which I am connected, as an example. This institution is conducting a series of impact tests on highway bridges; a special investigation into the properties of various typical soils in Iowa as related to highways and engineering structures; an extensive research on the theory of loads on culverts; and other broad researches on tractive resistances on roads, fuel consumption in motor vehicles as affected by road surfaces and grades; besides many researches in other lines of engineering.

Captain P. St. J. Wilson, of the U. S. Bureau of Public Roads: I have been requested to represent the American Association of State Highway Officials in place of Col. Uhler, whose death was announced this afternoon. I have been so recently requested to take Col. Uhler's place, that I really do not know just what the Association has been doing particularly. Mr. Mattimore, who spoke to you this afternoon about his work, is Chairman of the Research Committee of the American Association of State Highway Officials, and the work of the Association through him is connected with the work here. The State Highway Officials Association is made up of a comparatively small number of officials, and as a body, their funds for research work are quite limited. The individual states are cooperating with the Bureau of Public Roads and State Highway Departments, and are getting valuable information. The Association can save a great deal of money for the country.

Mr. Prevost Hubbard, representing the American Society for Testing Materials: There are a number of committees of the American Society for Testing Materials whose work is directly or indirectly related to highway research; committees on iron and steel, concrete and concrete aggregates, brick, timber, drain tile and a number of others. Perhaps, however, the work of Committee D-4 on road and paving materials is the most closely related to highway research. This committee is composed of sixty members and its work is divided under two subcommittees, one on non-bituminous road materials and the other on bituminous road materials. Both sub-committees are divided into a number of sectional committees, to each of which is assigned some individual research problem in connection with the standardization of tests, methods of sampling, or specifications for highway materials. There are in all approximately forty of these sectional committees now at work. During the past three years Committee D-4 has been especially active, and I believe I am safe in saying that during this time no other committee of the Society has been responsible for proposing a greater number of methods of testing, methods of sampling and specifications. Already, as a result of the committee's work, the Society has adopted three standard specifications and seventeen standard methods of tests and sampling. In addition there have been proposed twenty-five tentative specifications and ten methods of tests and sampling.

The work of the committee is not yet complete, as there are a number of tests and specifications which are not at the present time either in tentative or standard form. The committee is endeavoring, however, to hasten its work as much as possible, so as to make available its tests and specifications for the use of workers in other fields of highway research, as well as for the regular producer and consumer of highway materials.

Dr. H. C. Dickinson, Research Manager, Society of Automotive Engineers: Some time ago the Society of Automotive Engineers established a Research Department as an integral part of its headquarters organization. The purpose was to centralize the research activities of the industry, of the various manufacturers, and of the educational institutions, et cetera, which were working on problems of interest to the automotive engineers, and to consider the establishment of a systematic research program which might make for the eventual progress of the industry.

One of the first questions was: Do we intend to organize an independent research laboratory? And that was answered negatively. Research facilities are fairly extended, and the Research Department has therefore aimed to aid in the solution of the general research problems of the industry as a whole through the systematization of the existing facilities. A number of projects have been under way.

One problem, which happens to be the main activity of the Department, may merit a few words of explanation because it is typical of the sort of problem which we wish to undertake.

The quality of gasoline is, of course, a matter of common, everyday discussion. In the interests of the petroleum industry, the automotive industry, and the car owner, it is necessary to determine what kind of gasoline will give the average vehicle the greatest number of miles of transportation per barrel of crude oil used in the production of this fuel. The Society of Automotive Engineers, in conjunction with the National Automobile Chamber of Commerce and the American Petroleum Institute, organized an extensive program to arrive at the solution of this problem. This program includes very precise and scientific road tests of vehicles and tests of fuels, which are being conducted by the United States Bureau of Standards, the United States Bureau of Mines, and other government departments, with the support and cooperation of the three organizations previously mentioned. This program is now virtually complete, and results will be published shortly.

In addition to this cooperative project, the S. A. E. Research Department arranged for similar tests by several of the companies which manufacture automobiles. Each undertook to make series of service tests with cars of their own make, using for test purposes four fuels of varying volatility and keeping careful record of the results obtained with each fuel.

Tests were run last summer, and a series will be run in winter weather, so that accurate record may be kept of the effect on car performance of temperature fluctuations when different fuels are used.

One other project of the Research Department which should appeal particularly to this committee is an investigation of road surfaces. We are anxious to find out if the non-skid devices should properly be applied to the tire or the road; what modifications of road traffic regulations are necessary to make traffic safer; what various types of trucks cost to operate; the stresses to which tires are subjected on different types of roads and with different types of load. These are a few topics picked at random from our Highway Research program.

Our Highways Committee has only just begun to operate, but we wish to cooperate in the most efficient and effective way possible with the organizations now engaged in that important field.

Mr. Charles M. Manley: Dr. Dickinson asked me to make a statement for the Society of Automotive Engineers. In Dr. Dickinson's remarks he omitted one thing in which the automotive engineers are very keenly interested, and which is of great importance to them, and that is operation also, including maintenance of vehicles. The society is giving attention to this very important field of operation, which will, I believe, within fifteen years, possibly less, be a great deal bigger than the making or the selling of them.

Mr. Nelson P. Lewis, for the American Society for Municipal Improvements. While the name of this Society might give the impression that its interests and activities are confined to what might strictly be called "municipal improvements," the subject of highway improvement makes a strong appeal to the Society, and its interests extend not only to city streets, but to interurban, state, and even national highways, or to the approaches to and exits from cities and their connection with each other and the rest of the country. As indicating the degree of such interest and activity, the Society has the following standing committees or sub-committees on specifications:

1. Bituminous pavements, including surface treatment.
2. Brick pavements.
3. Cement concrete pavements.

4. Stone block pavements.
5. Wood block pavements.
6. Sidewalks and curbs.
7. Sewers.
8. Sub-grade and foundations.
9. Street railway pavements and track construction.

It also has two special committees on standard tests, one for bituminous materials and another for non-bituminous materials.

Mr. Ward P. Christie, Research Engineer of the Associated General Contractors: Investigations by the Associated General Contractors of America, in the field of construction economics, have been especially directed toward the improvement of construction methods and elimination of wasteful habits or practice in the highway industry. The principal problems now under consideration are:

(a) Lengthening the construction season.
(b) Reducing seasonal fluctuation.
(c) Breaking down the peak demands for material transportation in late summer.
(d) Inducing other industries to distribute transportation demand.
(e) Developing winter methods of construction.
(f) Reducing labor turnover and idleness by performing all possible work in the winter season.

These problems, the solution of which in a measure depends upon cooperative action between the various elements of the construction industry, the railroads and other industries, are primarily concerned with the reduction of highway costs. Results of the investigation so far made are qualitative rather than quantitative, as the data and statistics available are very meager. The tendency and general results of instituting the action implied in these subjects, however, has been clearly determined, and the Association hopes to develop information which will indicate the amount of saving possible.

Mr. W. O. Hotchkiss, representing the Association of American State Geologists: The interest of State Geological Surveys in highway research varies greatly. In a few states, as Missouri, Wisconsin, Maryland, and North Carolina, the state geologist played a large part in inaugurating the state highway program. This has given the geologist a keen appreciation of the help that he can give the highway engineer, and much has been done in these and other states in looking up various local materials that may be available for road construction. These materials are concrete aggregates—sand, gravel, and various kinds of rock suitable for coarse aggregate—and material for sand-clay roads and gravel roads.

The various geological surveys are glad to do everything they can when called upon by the highway engineer. The chief difficulties are that the geologists know too little of the highway needs, and the highway engineers know too little of what help the geologist can render. The result is that there is far too little cooperation for the good of both. The highway departments have occasionally employed geologists who were ill-fitted to do the work needed, and since to the highway engineer all geologists are alike, the Department consequently has no very high opinion of geologists in general. This is about the same as though a business man needing a sewer system for a large plant were to employ an engineer graduate to design it, and because the poor fellow was an electrical engineer and gave him the kind of service that might be expected, should condemn all engineers. I would caution highway departments that there are many varieties of geologists, and good, medium, and poor grades of each of these varieties. If a geologist is needed, be sure to get one who is properly qualified to get the results needed.

Mr. Fred M. Rosseland, representing the National Safety Council: The National Safety Council has a membership of some 3,500 members, employing six million workers, and also has thirty-four local councils in as many different communities. We have sixteen industrial sections of our membership in addition to our Public Safety and Educational sections. More than one thousand leaders in safety work are serving on the Council's committees and in its sectional activities and many more executives serve the local councils.

Our Engineering Section was organized with the same high standards set up by the National Engineering Societies and has been maintained on that plane, so that its members can speak authoritatively from the technical standpoint. Our library is filled with the accident prevention experience of our industrial membership, plus much material on public safety—all of which will be available.

Dean A. N. Johnson: My work has been in cooperation with the Bureau of Public Roads and the State Roads Commission of Maryland. We have made a traffic study and have produced a traffic map showing the flow of traffic over the state highway system. There are about 180 stations at which counts have been taken for a number of years. Since this map was made, counts have continued and we expect to produce another map with two years' additional data. We shall then have a fairly definite curve of increase of traffic.

Another project that has been under way is a study of concrete roads of Maryland. There were in operation, during the past two summers, trucks with core-drill outfits which have taken samples of cores over the entire state highway system. About one-half of the work was done a year ago, and half the work was done this past summer, which has resulted in securing about 1,600 core samples. The estimated total cost of core sampling, that is, of getting the sample in the field, bringing it to the laboratory, preparing it for testing and testing it, is approximately $5.50 a core.

There had been some similar tests made and some intimation that as the concrete had remained in service it was gradually becoming weaker. It was with the purpose of studying this phenomenon further that, in addition to taking the samples from the roads and getting the crushing strength, we have made some investigations of the elastic properties of the concrete, to determine particularly what effect continued traffic loading might have had. The field samples will be compared with the tests made in the laboratory under definitely known conditions. So far a comparison of results from tests of the samples secured from the roads has failed to indicate that there is any relation between the length of time the road has been in service and the strength of the concrete. In connection with the laboratory tests of the fatigue of concrete, we have devised a machine from which some very significant results are expected.

ELECTION OF OFFICERS

Report of Committee on Nominations.

The following nominations for officers of the Advisory Board were reported by the Committee Chairman, Mr. A. T. Goldbeck:

Chairman, Dean A. N. Johnson.
Vice-Chairman, Mr. A. D. Flinn.
Executive Committee:
Mr. Henry M. Crane (renominated).
Mr. Thos. H. MacDonald (renominated).
Prof. T. R. Agg.

The report of the committee was accepted and the Director cast the ballot of the Board for the nominees.

Budget. Dr. Hatt: We shall require the following amounts of money for carrying out the work of the Board:

$15,000	for the expenses of the Director's Office.
20,000	for committee expenses.
$35,000	total.

$15,000 is in sight, leaving $20,000 to be raised by the Ways and Means Committee which will be appointed by the Executive Committee.

Chairman: The Chair understands that the place of the next meeting will be left to the Executive Committee.

Adjourned at 10:30 p. m.

BULLETIN
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ON THE FORMULATION OF METHODS OF EXPERIMENTATION IN ANIMAL PRODUCTION

REPORT OF THE SUBCOMMITTEE ON ANIMAL NUTRITION[1]

PRESENTED FOR THE COMMITTEE BY E. B. FORBES AND H. S. GRINDLEY

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FOREWORD

The point has frequently been made by research men that it is as impossible, as it would be undesirable, to standardize methods of research.

To the extent that research is an expression of individual personality and genius, standardization is as impossible, as out of harmony with the spirit of research, as is piece-work.

But research is not wholly, or even largely, an expression of personality and genius. However much these individual qualities may enter into the conception of research problems, research work itself is actually conducted, in the main, by orderly, methodical procedures, the underlying principles and many of the details of which may be definitely expressed, and must be clearly understood and faithfully followed, if the experimental program is to lead to consistent and comparable results.

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[1] Committee on Food and Nutrition, Division of Biology and Agriculture, National Research Council. Members of Subcommittee on Animal Nutrition are: E. B. Forbes, Director, Institute of Animal Nutrition, Pennsylvania State College, State College, Pennsylvania, Chairman; H. S. Grindley, F. B. Morrison, C. H. Eckles, and C. R. Moulton.

Those cognizant of the present status of research work in animal production agree that great improvement awaits the standardization and rationalization of methods—not as a means for the regulation of genius, but for the elimination of bad logic and inefficient procedure.

During a number of years this subject of improvement and unification of methods has been a feature of the work of the American Society of Animal Production, as provided for by its standing committee on Methods of Investigation; in fact, this paper was begun as a report of the aforesaid committee, and was taken up by the Committee on Food and Nutrition of the National Research Council, on the request of members of the Society of Animal Production, for the purpose of stimulating the project in several ways, but especially through the provision of funds to defray expenses of conferences.

This paper is presented, then, not as a complete and final expression on the subject, but as a condensed, preliminary treatise, intended as a logical starting-point for a further, continuous and more detailed consideration.

As to scope, this paper is especially in the field of the animal husbandman, and does not seek to treat of either chemical analysis or physiological research.

1. GENERAL PROCEDURE IN ANIMAL EXPERIMENTATION

PREPARATION OF PLANS

Clear, accurate, comprehensive, and detailed plans of the specific investigation which has been selected should be prepared. The plans, in a tentative form, should be submitted in full, for criticism, to the members of the department, and to the administrative head of the institution. No investigation should be started until the plans for the same have been matured and perfected. Each phase of the work of the investigation, as herein outlined, should be given careful and thorough consideration and study in the preparation of the plans.

STATEMENT OF PROBLEM

A prime requisite of successful investigation is a clear and definite formulation of the problem to be solved. An ambiguous question addressed to nature is likely to receive an ambiguous answer. The most successful investigation is likely to be one dealing with a single clear-cut problem.

STUDY OF THE LITERATURE UPON THE PROBLEM

The first essential in properly outlining an investigation is a thorough knowledge of the previous investigations on the specific subject and also on the closely related subjects. Such knowledge can be gained only by a thorough study of the literature dealing with the problem. In this study the preparation of abstracts of methods and results, and the compilation of a bibliography are always helpful, and are really essential to the proper recognition of that which has gone before.

CHOICE OF KIND OF ANIMAL AS SUBJECT FOR EXPERIMENTS

Certain lines of animal experimentation, especially such as have to do with fundamental principles of nutrition, requiring large numbers of individual subjects, purified food material, and long periods of observation (in terms of the life span) may be carried on with minimum expenditure of time, labor, and money with small animals such as mice, rats, rabbits, guinea-pigs, and poultry.

Thus experiments on the occurrence and quantitative distribution of the vitamins among foods and feeds have been conducted, so far, mostly with the smaller animals, since such work involves the use of expensive artificial food materials, but especially because vitamin deficiencies which are manifested by characteristic effects with these small animals have not yet been so definitely and generally associated with unequivocal symptoms in the larger farm animals.

Also, certain kinds of evidence as to the efficiency of feed constituents, such as protein and mineral substances, for maintenance, growth, lactation and other physiological processes, can advantageously be obtained from work with small laboratory animals. In all such investigations, however, there is a question as to the applicability of the results to the larger, slower-growing farm animals, and their confirmation as bearing upon these species, in all practicable ways, is essential to the deduction of safe guides for use in animal production.

Differences in susceptibility to such influences as vitamin deficiency must also be considered; and we must bear in mind the fact that while the fundamental laws of growth are in all probability quite similar, if not identical, for farm animals and for small laboratory animals, our practical interests are not confined to those fundamentals in which all mammals agree, but are based largely upon physiological superficials—upon differences in emphasis, or accentuation, of the same set of fundamental principles.

The economic usefulness of results of nutrition investigations is not necessarily assured by the establishment of the fundamental principles involved, but is apt to require a demonstration of *facts* of interest as applying to the *species* of interest.

It is well, therefore, in the choice of the species of animals to be used in a nutrition investigation, to bear in mind the fact that there are advantages in using as subjects, when it is practicable, the species to which the results are to be applied. In this connection the experimenter should also have in mind the audience whom he would reach with his results. The agricultural public is more easily and effectively reached with results of experiments with farm animals than with results from investigations with other species which, because of considerations of economy of time, labor, and money, are more commonly used for laboratory studies in the field of nutrition.

Other considerations which may enter into the choice of kind of animal for experimental use are rapidity of growth, reproduction or other increase, the vigor of response to feed, and adaptability to the necessary restrictions of the experimental routine.

In the study of problems relating specifically to animal production, such as, for instance, the digestibility, comparative nutritive values, or net energy values of feeds, the relative utilization of feeds for different forms of production, the specific feed requirements for maintenance and production, or any problem involving economic aspects of feeding for production, the use of farm animals as subjects is, of course, imperative.

Breed and type of animals.—Experimental lots of animals to be used as a means for the comparison of feeding or other conditions must be of the same type and breed. Diversity within the lots should be restricted in all practicable ways, in order to reduce the number of varying factors involved, and close blood relationship is a desirable condition. The uniform distribution of litter mates among the lots is one means of contributing to this end. A definite and accurate description of each animal should be recorded at the beginning of the experiment.

Sex.—Experimental subjects should be so chosen that their sex shall not constitute an unequal or an unnecessarily disturbing influence. The bearing of this principle differs with the age and species.

Age.—Except in studies of the influence of age it is imperative that all of the animals serving as subjects in an experiment be of practically the same age, since the rapidity, economy and composition of the increase, and even the cost of maintenance, are materially influenced by this factor.

The limits of variation permissible will increase with the age. Thus, at the age of three months the animals selected should be within one, or at the most, two weeks of the same age, while at two years a variation of two months is permissible.

In certain types of experiments the animals within the lots may vary in respect to age, but the several lots should be closely comparable in this regard.

The exact age of each animal should be known and recorded whenever possible.

Functional capacity.—In experiments on the effect of feeding, or other conditions, on the production of milk or butterfat, the different lots of animals should be not only of approximately the same age and breed, but also of approximately the same functional capacity, and at the same stage in the period of lactation. In certain types of investigations which involve comparisons of results from a series of experimental periods with the same animals uniformity of breed, type, sex and age of the subjects on which such series of observations are made may not be so important.

Previous treatment.—The experimental animals should preferably be selected from the same herd or flock. If it be necessary to select animals from different herds or flocks, or from different localities, they must be submitted to a preliminary feeding period of from one to four or more weeks (depending upon the nature of the investigation) during which all must be fed alike.

Due observance should also be accorded the fact that this previous treatment, as affecting nutritive and physiologic reserves, may determine the nature and extent of reaction to the conditions of the experiment. In recognition of this principle it is well that animals serving as subjects for experimental work should have been so reared or treated as to be in a state of nutrition fairly representative of those animals to which the results are to apply in practice. In experiments involving drafts upon nutritive reserves the whole history of growth of the subjects may be of importance as affecting availability for the purpose. In experiments involving irksome confinement, adequate time should be allowed for adjustment to the experimental conditions. In short, the establishment, within the experimental subjects, of a definite and favorable nutritional basis or background against which results are to be observed and measured is essential to the most satisfactory conclusions, and is often as important as the results of the experimental treatment itself.

Only animals which are apparently healthy and normal, and apparently functionally alike, should be selected for experimental use; and any such tests as may be found effective to prove them so should be made. (See under Preliminary Feeding, Feeding Experiments, page 36.)

MANAGEMENT AND CARE OF EXPERIMENTAL SUBJECTS

In the care of the subjects of an experiment we should seek to exclude all influences which would affect results unequally, or otherwise in such manner as to tend to obscure a clear-cut response to the experimental inquiry.

The handling of the subjects of an experiment should be entrusted only to attendants who understand the behavior and requirements of the animals involved, and whose kindliness and regularity may be depended upon absolutely.

A considerable measure of restraint of the animal's activities is often essential to the conduct of exacting experiments, and it is important in preserving the hearty cooperation of the subjects that they be treated with consideration, and that they be assured in ways that they understand that all is well and that they are in friendly hands. Animals learn, some of them very quickly, to appreciate the spirit of the caretaker.

Radical changes of environment tax the adaptability of animals just as they do that of human beings. In experiments of a refined nature, sufficient time should be allowed the subjects of the experiment to become thoroughly accustomed to the changed circumstances necessary to the conduct of the investigation, so that they may feel at home, before the experiment begins. A restless animal, out of harmony with its environment, is unfit for use in a study of normal processes.

In general, all influences which tend to increase the sense of well-being of the experimental subjects are conducive to liberal and uniform production, and in this way favor consistent and satisfactory results. The care of the animals and their response to the feed are of such importance that some one who is responsibly interested should give these matters his personal attention.

The methods of cleaning of the animals and their surroundings will naturally vary much with the nature of the investigation. The principles of importance are that the cleaning of the animal adds greatly to his comfort, and thus to his reliability as an experimental subject, and that the quarters used in some kinds of investigations, metabolism experiments, for instance, may impose such restraint upon the animal that he will be unable to clean himself in his habitual ways. For instance, a pig, in a metabolism crate, is unable to free himself from skin secretions, as ordinarily accomplished by wallowing. He therefore becomes very dirty and uncomfortable unless regularly and thoroughly cleaned.

In exact experiments no bedding materials which the animals can eat should be used, and the stalls or crates should be so constructed that no wood or other material foreign to the investigation can be gnawed and eaten, thus contaminating the excreta.

Water should be supplied to experimental animals in a satisfactory quality, and in unlimited amounts, except in studies of water requirements. Distilled water should be given in investigations involving mineral metabolism. Water should be given at regular times or should be accessible at all times.

In the feeding of experimental animals important considerations are that the weighing be done by a responsible person, that the feeding be carried out with regularity, that waste of feed by the animals be prevented, and that refused feed be accurately accounted for.

The consumption of salt should be controlled by some orderly process. If it be fed mixed with the feed it must be known that the amount given is satisfactory. It must not be assumed that the effect of mineral supplements given with the feed will be the same as though fed separately. The effects differ in important ways.

It is essential in all investigations of normal metabolism that the animals experimented upon shall remain in all ways in that perfectly healthy state to which the results are to apply.

When the exercise afforded by the method of the experiment is insufficient for the maintenance of normal functional activities the animals must be given such additional exercise as they require, at regular times and in the same manner each day.

THE TAKING OF LIVE WEIGHTS

The accurate determination of the live-weight of an animal is indeed a difficult matter, on account of variations in the content of the alimentary tract and bladder. Important considerations in this connection are (1) that weights must be taken under as nearly uniform conditions as possible, with reference to feeding and watering, (2) that the more nearly empty the alimentary tract of the animal, the less is the possibility of variation in live-weight, (3) that the average of several weights is usually more valuable than a single weight, and (4) that in refined experiments of an exact nature the taking of frequent (preferably daily) live-weights, thus allowing of the plotting of a curve to indicate the increase (or decrease) is the most satisfactory method, and is recommended where this procedure is practicable.

When experimental animals are unused to the weighing process an error in the use of averages of—let us say—three to five weights, taken on consecutive days, may result from disturbance of eating, drinking, and elimination of excreta. Under such circumstances animals of nervous disposition may give widely varying weights the average of which may less closely approximate the true weight than does the first weight of such a series. Under the same circumstances other animals of more phlegmatic disposition may give remarkably consistent weights, day after day. (See also Live Weights, Feeding Experiments, page 38.)

SELECTION AND SAMPLING OF FEEDS

The feeds selected should be of the best available grade, unless different grades are being compared; the apparent quality should be observed and recorded, and the composition should be determined by chemical analysis. Before the beginning of an experiment a sufficient quantity of each of the feeds should be selected, from one source if possible. In these provisions due recognition should be accorded the fact that feeds vary greatly in composition, and that the relative values of feeds may be reversed by the quality and composition of the particular lots involved. The extent of the necessary chemical control of food composition will naturally differ much with the nature of the investigation. If the feeds be of satisfactory quality at the beginning of an investigation, and are stored under conditions which prevent deterioration, repeated analyses during the course of the experiment will be unnecessary, but in all exacting work the moisture content should be determined, or controlled, since air-dry foods in storage may gain or lose many per cent of this constituent.

In the sampling of feeds for analysis, the size of the sample should be consistently determined in accord with the fineness of division of the material. In the mixing and the final sampling it is also desirable that each shovelful, or other portion moved, should represent as nearly as possible the full depth of the pile. The taking of samples by handfuls from the top of a pile is not a well-considered procedure.

CONTROL OF MOISTURE IN SAMPLING

The proper control of moisture in materials to be analyzed requires equipment which is not ordinarily available. Under the conditions of most experimentation very considerable errors are likely to enter into the work on account of the inadequate moisture control, especially through loss of moisture during the final grinding.

A consistent method of obviating this difficulty would be through making a complete moisture estimation, in a vacuum drier, on a large quantity of the material, in the condition as entering into, or as produced in, the experiment. This material would then be finely ground, and so preserved. A second moisture estimation would be made at the time the finely ground samples are weighed out for analysis.

A fairly satisfactory compromise procedure is to dry weighed portions of the coarse materials, in quantity and condition as above mentioned, to an extent sufficient to stop the growth of organisms. The material is then permitted to come back to air-dryness under the conditions of the grinding room, and is weighed again, before the final grinding is performed. After this final grinding the materials are preserved for analysis in the condition as delivered by the mill, no account being taken of the loss of moisture during grinding—which may introduce serious errors, especially in the case of tough materials which develop considerable heat during the grinding process.

THE PRESERVATION OF ANIMAL PRODUCTS FOR CHEMICAL ANALYSIS

A general rule to follow in the preservation of animal products for chemical analysis is to arrange that the analytical work begin at the earliest practicable moment after the collection of the materials; and that these materials be sampled, and analyzed from their natural, fresh condition whenever practicable, in order that they may undergo the least possible amount of chemical change. Animal products are characteristically unstable in storage, and their preservation for analysis often involves problems which are difficult of solution without undesirable compromise.

On account of practical considerations, however, it is usually necessary to preserve experimental products for some time before analyses can be completed, though some estimations on some products (an ammonia estimation on urine, for instance) must be made on the perfectly fresh material, and with the least possible delay, on the day of its collection.

The methods of preservation which give satisfactory results differ much in accord with the product and the particular estimation which is to be made. In general the least objectionable method of preservation is by the use of cold. We must not think of practicably attainable cold as suspending all chemical change, however, since as a matter of fact, certain enzymatic activities proceed freely at temperatures far below the freezing-point of water. In the use of cold for the preservation of animal products for analysis a few observations worthy of consideration are the following:

1. Most animal products which are being held in cold storage, for chemical analysis, should be kept at the lowest available temperature, in order to minimize chemical change. The cleavage of both fat and protein proceed slowly at very low temperatures.

2. Frozen materials may lose their water by evaporation; thus thick coatings of frost accumulate on the inside walls of sample containers in a cold-storage room. This moisture must be carefully reincorporated into the sample whenever portions are removed for analysis.

3. Freezing alters the physical condition of the constituents of milk in such manner as to make it difficult to get satisfactory samples.

4. Freezing may precipitate constituents from urine which cannot be redissolved by warming.

5. For satisfactory refrigeration materials should be suspended, or set upon shelves, so as to be surrounded by cold air. The effective-

ness of the refrigeration may be greatly reduced by setting the materials upon the floor or against a wall.

6. The most efficient refrigeration of meat is accomplished by cooling as rapidly as possible, without freezing. The most desirable temperature at which to hold meat is 30°- 32° F.

Certain products, feces for instances, and also samples of ground animal tissues, may be fairly satisfactorily preserved by drying, especially for permanent preservation for emergency or reference purposes. Limiting factors applying to the employment of drying as a method of preservation are (1) the loss of volatile constituents other than water—ammonia and volatile fats, for instance, (2) gain in weight of fats through oxidation, (3) the loss of finely divided portions of the sample during transfer and mechanical reduction, (4) the labor necessary to effect the complete mechanical transfer of the dried materials, (5) the difficulty of bringing some materials to complete dryness (as with urine, for instance) on account of a syrupy or gummy condition, and (6) the refractory physical character of some products in the dry form.

Chemical substances are used for preservative purposes in milk and in urine, special purposes requiring treatment adapted to the particular end in view. For general analytical work milk is preserved with formalin, potassium bichromate, or corrosive sublimate, either alone or supplementary to refrigeration. (See also page 26.) Urine may be satisfactorily preserved for most purposes by the addition of 2 c. c. per liter of a 5 per cent solution of thymol in chloroform, preferably with refrigeration. Urine is so complex, however, and presents so many peculiarities, as determined by the species of animal and character of ration, that no one preservative treatment will serve all purposes.

Alcohol has been used for the preservation of the excreta of poultry, as the daily collections are made, during an experiment, the preservative being subsequently driven off by heat in the preparation of the material for analysis.

Length of Experiments

The earlier work in this field was generally characterized by insufficient length of experimental periods—a condition which still prevails in many investigations. In the better class of work there is manifest a marked tendency toward a narrower and more critically defined field of inquiry, more elaborate and carefully considered methods, greater numbers of experimental subjects, and much more extended periods of observation.

It is now recognized that the more important animal functions are so protected by reserve and safety provisions that very long experimental periods are required to determine final nutritive effects of some sorts. For fundamental investigations, having to do with growth, the experimental period should cover the complete life cycle; studies of milk and egg production also gain significance through similarly protracted periods of observation. In general there is a tendency to extend the inquiry over the whole of the life process involved, where this is practicable. Where, as in metabolism investigations, the expense of long-continued experiments with large numbers of animals would be in most cases prohibitive, a discontinuous series of shorter periods may be used to obtain results typical of the several stages of the process of interest.

Processes which are completed in the animal economy within a short time, such as digestion, assimilation and elimination, for instance, may be effectively studied in brief periods of observation. Energy balance data of satisfactory accuracy may also be obtained in very short periods of observation, with adequate equipment.

While longer periods of observation than are commonly used are often desirable they should not be prolonged more than is necessary to obtain accurate results, for the reason that, in work of certain types, if the periods are unnecessarily long the cumulative effects of unknown or imperfectly controlled factors may compromise or obscure the characteristic reaction of the subject to the influence under investigation.

In all investigations, of whatever nature, the work should be planned with careful consideration of the time element, and provision should be made for the avoidance of the error of judging a whole process by the measurement, however accurately, of an atypical portion.

ALTERNATING EXPERIMENTAL TREATMENTS

In certain types of experimentation, rations may be alternated or rotated between or among the two or more experimental lots of animals, thus providing a means for the reduction of experimental errors due to individuality of the subject, and furnishing bases for the comparison of rations in spite of continuously progressive change (1) in plane of nutrition, (2) in rate of production, or (3) in composition of increase.

There is least question as to the propriety of this method of procedure in studies of the simpler problems of metabolism, such, for instance, as relate to digestion and to paths of elimination. It is

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frequently used, for lack of a more satisfactory method of procedure, in those very difficult problems, such as abound in the field of milk production, in which conclusions must be drawn from observations of slowly cumulative effects of rations or treatments, or of comparative rates and directions of change in progressively and periodically varying functions.

In employing this method the length of the necessary intermediate periods will vary from perhaps one week to an indefinite number of weeks. Lack of evidence as to just how long these intermediate periods should be, makes it necessary, in the interest of safety, to maintain a critically conservative attitude toward the determination of the length of these intervals, and to make them as long, rather than as short, as practicable.

An especially difficult field in which to use this method with assurance is in problems of milk production, in which it may take a month to realize the full effect (in an ordinary sense) of a change of ration on the amount of milk produced, and in which the annual cycle of reproduction and lactation is really the metabolic unit, in point of time, the terms of one such cycle or unit markedly affecting conditions in the next one succeeding.

THE RECORDING, CALCULATION, AND TABULATION OF EXPERIMENTAL DATA

All data and observations should be carefully, fully, and legibly recorded, in a systematic manner, at the time they are made, in proper record forms. Such original experimental records should be kept in a fire-proof vault; or, if this is not possible, duplicate copies should be made, each day, for storage in such place of safety as is available. In so far as possible, printed blank forms should be used in recording the data.

These data should be posted promptly on record sheets or in note books; and the calculation and tabulation of the results should be carried forward without delay, so that the results may be of use in directing the course of the experimental work from day to day, or week to week.

All such records should be proof-read, for the detection of errors, and the fact of such checking should be recorded.

Duplicate readings, by different observers, should be made on weights or other data in all cases in which these results cannot be checked later.

Where practicable, results should be computed in duplicate, by independent computers. This is much preferable to having one computer check another's work directly.

MATHEMATICAL ANALYSIS OF RESULTS OF EXPERIMENTS[2]

In the interpretation of evidence in experiments in the field of animal production a certain measure of ambiguity in the significance of data results from dissimilarity in the behavior of experimental subjects under the same treatment, due to individuality, and to other uncontrolled inequalities in experimental conditions.

In drawing conclusions the experimenter ordinarily averages the groups of data to be compared, and uses his judgment as to whether the differences between these averages are sufficient to warrant safe deductions. In such an informal procedure it is inevitable that the temperament, personal bias and experience of the investigator should enter into the adjudication of the results. Thus wide differences may exist in the opinions of investigators as to the significance of the difference between two groups of data. Clearly, the unaided judgment is incompetent to draw infallible conclusions from extensive and complicated numerical materials; and it is most desirable, in the interest of safety of conclusions, that we avail ourselves of the assistance of mathematical analysis of experimental data.

In this connection especial attention should be given the use of averages, the measurement of variation, and the computation of the probable errors of averages and of differences between averages. The coefficient of correlation is also indispensable in the study of associated phenomena.

Averages.—Averages should be used with extreme caution. Their use for comparative purposes is often misleading. The individual data contributing to an average must be known, since it is only through the study of the individual data that the true significance of the average may be determined. Hence in the publication of experimental reports, individual data, whenever practicable, as well as average data, should be included.

Variation and its measurement.—In the comparison of groups of data it is necessary to calculate not only their averages but also the variation of the data within each group, thus measuring the influence of the uncontrolled factors in the experiment. A good measure of variation, for this purpose, for groups of data containing 8 or 10 or more individual determinations is the standard deviation, which is the square root of the average squared deviation of all individual data from the average for the group.

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[2] Adapted from Ill. Agr. Exp. Sta., Bul. 165, by H. H. Mitchell and H. S. Grindley; see also H. L. Rietz and H. H. Mitchell, Journ. Biol. Chem. 8 (1910-11), 297.

Coefficients of variation.—For extensive comparisons of variation, especially when involving different experimental conditions, the coefficient of variation is used. This coefficient is the standard variation expressed as a percentage of the average.

Coefficient of correlation.—The coefficient of correlation, obtained by the so-called product-moment method, measures the extent to which variation in one character is associated with variation in another character. This coefficient, r, is equal to the mean of the products of deviations, from their respective means, of corresponding variates in two sets of data, divided by the product of the standard deviations of the two groups. With perfect correlation $r = \pm 1$, within limits of experimental error, the sign indicating whether the relation is direct or inverse. When there is no correlation $r = 0$, except for the effect of experimental error. For other cases r assumes values between $+1$ and -1, approaching these limits as the correlation approaches completeness. If the two sets of data correlated are normal in distribution a probable error of the coefficient of correlation may be calculated, for the purpose of defining its significance, by assessing the uncontrolled effect of experimental error.

The probable error.—The probable error of an average of results from an experiment is that value which when added to and subtracted from the average defines two limits such that the odds are even that in a repetition of the experiment the average or other result will fall between them. The probable error of an average is obtained by multiplying the standard deviation of the constituents of the average by the factor 0.6745 and dividing by the square root of the number of data upon which the average is based. The probable error of differences between group averages may be calculated by squaring the probable errors of the averages involved, adding, and extracting the square root of the sum.

If we add to and subtract from an average datum 3.17 times its probable error there are obtained two limits such that the odds are 30 to 1 that a second experiment will give an average result falling between them. For odds of 20 to 1 and 10 to 1 use the factors 2.95 and 2.55, respectively.

Repetition of Experiments

The necessary precision in feeding trials may be attained by a reduction of the experimental error or by repetition of the experiment.

From a study of the efficiency of repetition, it appears that often, even under apparently favorable conditions, the results of feeding experiments cannot be duplicated. Frequently experimenters have obtained results from feeding trials pointing unequivocally to a certain conclusion, and yet subsequent attempts to duplicate such experiments have yielded results quite incompatible with the first conclusion. The gravity of such a situation cannot be over-emphasized. Its remedy seems to be, in general, the effective recognition of the fact that the results of feeding experiments are more prominently affected by the experimental conditions than is commonly understood. These conditions should be more carefully reported than is customary, and such analyses of feeds as will indicate their quality should be made.

The conclusion that one feed is better than another, for a specific purpose, may be totally at fault if other samples of the two feeds are used, or if other types or breeds of animals, or animals more (or less) mature, be used, or if other methods of preparing the feeds or sheltering the animals be followed. Such possibilities should always be kept in mind, and the frequently observed tendency to generalize from data of a very specific description should be carefully avoided.

2. THE DETERMINATION OF DIGESTION COEFFICIENTS, AND NITROGEN AND MINERAL BALANCES

That portion of the food which is not eliminated in the feces is considered to be digestible, and a coefficient of digestibility is a percentage statement of the amount of this digestible portion. This conception, however, is one of limited value, since considerable amounts of digested material, which we have not learned accurately to estimate, are returned to the alimentary tract, and are eliminated in the feces. This factor or error is perhaps small in the case of fats, is certainly considerable in the case of nitrogenous components, and is so large, as applying to mineral constituents, that the idea of determining the digestibility of the ash of foods is without logical justification.

Also, in the case of poultry, a further complication results from the fact that urine and feces are eliminated together; and as much as has been accomplished in the chemical separation of these two excreta is to estimate the uric acid, which is the principal solid constituent of the urine,—the combined excreta minus the uric acid, for routine purposes, being considered to be the feces.

Properly speaking, then, digestibility, as ordinarily determined, should be designated, in accurate considerations, as *apparent* digestibility.

For the determination of balances of nitrogen or mineral elements all factors of outgo must be determined, since a physiological balance, like a bank balance, is simply the result of the subtraction of the outgo (drafts) from the intake (deposits).

The five factors of outgo which are or which may be considered in the estimation of these balances are feces, urine, milk, eggs, and skin secretions—that is, everything except the gaseous and heat outgo. Quantitatively the skin secretions are unimportant, and are ignored except in investigations giving especial attention to this factor. In such cases they are collected by bathing, and by recovery from specially constructed absorbent suits. Shed hair and scurf are collected and accounted for in the most intensive type of studies of balances of matter but are not involved in digestion or balance experiments as ordinarily conducted. In balance investigations involving lactation, or egg laying, the milk or the eggs produced are considered as factors of outgo. In much the greater proportion of balance studies, however, food, urine, and feces only are involved.

In the collection of excreta corresponding to the food of an experimental period both urine and feces may simply be saved as eliminated during the experimental period, or the feces corresponding to the food of the experiment may be marked off by the feeding of a colored, indigestible substance with the first feed of an experimental period, and with the first feed given after the termination of this period. Carmine and lamp-black are the marking substances ordinarily used. Of these, carmine has the wider usefulness. In accord with the nature of the ration and the color of the resultant feces the amount of carmine necessary for the marking of the feces is ¼ gram to 1 gram per 100 pounds of live weight.

This marking procedure is probably more accurate, with human beings, swine, and dogs, than is the use of a given number of days' defecation; but the latter method alone is available for use with ruminants and poultry. Either procedure has its limitations. The inaccuracy of basing results upon a given number of days' defecation is obvious, especially if the ration is such as leads to irregular intestinal activity; while in the use of a marking substance there is a slight tendency for this to pass ahead of the residues of the feed with which it was eaten, and thus to tinge the color of the feces resulting from feed eaten before the marking substance was fed. The marking substance must be mixed with the whole of the feed given at the time it is fed. It is usually possible to distinguish satisfactorily between the slight tinge referred to and the deeper color which marks the feed with which the marking substance was fed.

For the conduct of digestion or balance experiments special equipment in the nature of cages, crates, or stalls must be employed to prevent the subjects from contaminating the intake by gnawing wood, eating bedding, or any other substance foreign to the investigation, and providing for the convenient and accurate collection of the excreta without the contamination of one by the other, or of either by foreign matter.

In experiments on mammals male subjects are commonly used, unless female functions are specifically involved, on account of the greater ease of collection of the excreta from males.

For the determination of digestion coefficients alone less elaborate equipment is necessary, except with poultry, than in case the urine also must be collected, as in balance experiments. In the devising of equipment to serve these purposes preference is given to metal construction or covering. Iron, tin, and zinc may be used, but copper reacts readily with urine, and on this account is not used unless plated with tin; and the employment of rubber equipment has led to the contamination of the materials of the investigation with sulphur.

NUMBER OF ANIMALS

In digestion and metabolism experiments not less than three animals should be used in each lot. If practicable five or even more should be used. Results obtained from four, five, six, or more animals are much more reliable than those obtained with one or two, because of the reduction of the influence of individuality. In studies of fundamental physiological processes, however, of such nature as not to be characterized by considerable individual variation, the use of one, two, or three animals as subjects, especially in studies of long duration, may yield results of satisfactory character.

LENGTH OF EXPERIMENTAL PERIODS

The proper duration of experimental periods in digestion and metabolism investigations can be determined by a mathematical study of the variability of the amounts of the daily excreta. In the absence of such data we are without definite guides, and must rely upon the informal results of judgment and experience.

It is essential that the excreta of the collection period shall accurately represent the feed of the experiment—that is, that they shall be uncontaminated by residues from feed of other kinds, or of the same kind but from different rate of intake. These purposes require (1) a fore-period of sufficient length to free the alimentary tract and the "floating" or "circulating" nutrients of the system from the specific effects of previous feeding, (2) a collection period of length sufficient to reduce to negligible terms the errors of collection of excreta at the beginning and the end of the experimental period, and (3) an after-period of unchanged conditions as to feeding, care, etc., in case a feces marker is used, which shall last until this marker appears.

In the greater part of the published work an insufficient fore-period has been provided, for the establishment of proper experimental conditions, and likewise, an insufficient collection period to follow. It is impossible to say very definitely how long these periods should be. In the more careful work the fore-periods and intermediate periods have been not less than 7 to 10 days, and the collection periods not less than 10 to 20 days in extent. Any considerable shortening of these periods appreciably detracts from the value of the results. To obtain the same accuracy of result without a feces marker as with the same a greater length of collection period is necessary.

The greatest practicable length of an experimental period is that time during which the feed consumption can be maintained without change in amount or kind, the subject remaining in normal condition.

No change, either by way of increase or decrease, in the amount of feed given, can be made at any time during an experimental period without the introduction of error unless the plane of intake be returned to that prevailing during the fore-period, and be maintained at this level for a duration of time equal to the fore-period, before the termination of the collection period. Practically, the collection period is and commonly should be terminated at once if it becomes apparent that the previous plane of feed consumption is no longer practicable.

THE SAMPLING AND WEIGHING OF FEEDS FOR DIGESTION AND METABOLISM EXPERIMENTS

The feeds used in digestion and metabolism experiments must be thoroughly mixed so that each portion fed, or retained for analysis, will be of the same composition. Whenever feeds are weighed out for nutrition investigation, samples must be taken for moisture estimation. On this account it is desirable that all portions of feed which are to be administered during an experimental period be weighed at one time. In other words, the feeds or the rations must not vary in chemical composition during the experiment in which they are used, and the samples of the feeds taken for chemical analysis must represent exactly the foods as they are weighed out for feeding.

The following is an approved method of mixing, sampling, and weighing grains, either whole or ground, for critical work; other methods, as carefully considered, however, may be as useful.

The amount necessary to one experimental period is spread out to a thickness of six to twelve inches on a clean, and perfectly tight floor. It is then shoveled systematically by two men standing on opposite sides of it who throw alternate shovelfuls of the grain into one pile. The grain is then spread out again, divided into quarters, mixed from opposite sides and the two resulting piles combined into one. This last procedure is repeated. The grain is then spread out into three approximately equal lots. The weighing of the individual feeds for each of the animals for an experimental period is begun immediately after it has been thoroughly mixed as described above. Special care should be taken in the weighing to have the individual feeds as nearly uniform in character as possible. With this in view, a part of each feed may be taken from each of the three piles. The individual feeds may be kept in bags of paper or cloth, or in covered pails, properly labeled to designate the animal for which the feeds were weighed. After the weighing of every two or three portions, a small amount of the thoroughly mixed grain may be taken from each of the three piles to form a composite sample for chemical analysis.

Hay, silage, stover, etc., must be cut into lengths of one inch or less, since it is impossible before cutting them to prepare samples of these feeds which are accurately enough representative of the whole amount to be satisfactory in digestion and metabolism experiments. The cut hay, stover, etc., may be sampled and weighed as outlined above for grain feeds.

Large samples of roughage should be saved for analysis, and, for the proper control of moisture content, should be weighed when first sampled and again just before grinding for the final sampling.

Silage is difficult to handle in carefully controlled experimentation. It may be weighed daily, with the saving of daily samples, later to be combined for the final sampling; or the individual portions may all be weighed at the beginning of an experimental period and preserved by freezing, the sample for analysis being taken at the time of weighing.

After weighing, the individual portions of feed, of whatever nature, must be so stored as to protect them from injury by dampness, from contamination by dust, and from loss through the work of rats, mice, and insects.

In connection with the grinding of the grain, it is well to bear in mind the facts that the fineness of grinding will determine, to a large extent, the fineness of division of the residues in the feces; and that extreme fineness of grinding will decrease the apparent crude fiber content of both feeds and resulting feces.

For the less intensive studies less exacting methods of handling the feeds than specified above will naturally commend themselves. The greater the refinement of the methods followed throughout an investigation the greater will be the value of the results, and the longer will they continue to be of value; but there should be a consistent and uniform expenditure of effort directed toward the refinement of methods lest insufficiency in some provisions shall serve to set at naught and render pure waste the disproportionate effort applied to other details of procedure.

SALT AND OTHER MINERAL NUTRIENTS IN METABOLISM INVESTIGATIONS

In metabolism investigations involving the mineral nutrients the mineral components of the ration should be separately weighed for each feeding. It is not satisfactory simply to weigh these constituents mixed with the ration. On account of the relatively small amounts involved, their concentration, and in some cases their physical character, it is impossible adequately to control the daily amounts consumed except by such separate weighings.

In some cases it is permissible to make one weighing for a day, and then to approximate the subdivision of this daily amount into the two or more feedings given during the twenty-four hours, but even such compromise is apt to result in error, on account of unforeseeable contingencies. The separate portions of salt and other mineral nutrients may be conveniently stored in small bottles or in coin envelopes.

THE COLLECTION AND HANDLING OF URINE

Whatever the method of collection of the urine especial care must be given this readily fermentable product in order to maintain it in condition for analysis. For the estimation of some organic constituents urine must be perfectly fresh; and for the estimation of hydrogen ion concentration it must be both fresh and undiluted. In no case is extensive fermentation permissible, since this is apt to lead not only to chemical but to undesirable physical change. No one preservative treatment of the urine will answer all purposes, since this product varies much in composition according to the kind of animal and ration; for most purposes, however, preservation with thymol-choloroform mixture,[8] preferably with refrigeration, is sufficient; and the most commonly encountered physical condition requiring correction, namely, the precipitation of phosphates, may be successfully removed by the addition of small amounts of acetic acid.

In metabolism experiments with swine or sheep, the urine should be received in glass bottles which have been coated with thymol by rinsing with alcoholic thymol solution, and drying.

In metabolism experiments with steers and horses, the urine should be conducted through an Armsby rubber funnel into thymol-coated bottles, or enameled pails provided with two-inch circular holes to admit the end of the rubber funnel. The pails should be placed under the stalls in enameled dish pans which serve as catch-traps in case of accident.

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[8] J. O. Halverson and J. A. Schulz; Journ. Am. Chem. Soc., XLI (1919), 440.

In experiments in which the excreta are caught by attendants, tin, galvanized iron, or enameled pails may be used for the collection. The urine will be transferred to thymol-coated bottles.

In experiments with cows a scoop shovel is useful in collecting excreta passed while the animal is lying down, and may be supplemented by an emergency pan, the bowl of the scoop shovel resting in the pan.

In warm weather the addition of chloroform-thymol solution to the receiving bottles used in connection with the crates or stalls helps to prevent fermentation.

The urines collected as above may be taken to the refrigerator at regular intervals during the day, or only at the end of the experimental day, as determined by the weather, the character of the urines and the conditions of the investigation. The used containers are exchanged in each case for clean ones which are likewise coated inside with thymol. At the end of the experimental day the urines are mixed, measured, and sampled. Certain samples may be used for daily chemical or physical determinations; other daily aliquots will be retained in the cold storage room until the end of the experimental period. During this time it is desirable that the urines be not frozen as this throws down solids which it may be difficult or impracticable again to get into solution. The temperature, therefore, should be as close as possible to the freezing point, but above rather than below the same.

At the end of the experimental period the daily aliquot samples of urine are removed from the cold storage and are combined, mixed, and sampled for analysis. For the protracted preservation of the composite samples a temperature just above freezing will be satisfactory for many purposes; for others the lowest attainable temperature may be necessary. The requirements for the preservation of urine for specific purposes should be determined by actual trial.

Quantities of urine are much more readily ascertained by volume than by weighing, the chemical analysis being performed on portions likewise measured by volume. There is commonly no occasion in quantitative studies for the estimation of either weights or specific gravity of urine.

All receptacles and apparatus used in the collection and transfer of urine may be cleaned with distilled water, the cleaning water being added to the main portion of the urine before it is measured. The combined urine and rinsing water may then be made up to volume in graduated flasks; aliquots for preservation and analysis may be taken by volume, and individual portions for the chemical determinations may be measured by volume, either directly from the sample, or after an intermediate measurement and dilution in a graduated flask. The advantages of this volumetric method of handling over any gravimetric procedure are, for most purposes, very great. The disadvantages are that the normal concentration of the urine is lost and that the integrity of the samples depends upon the purity of the distilled water used in completing the collection or transfer.

For some purposes it is desirable, as previously suggested, to make separate samples and analyses of the main portion of the urine, and of the rinsing water. When a portion of the urine is taken for certain estimations prior to dilution with rinsing water the mixing of the remainder of the urine and a part of the rinsing water must be done, of course, on a correct aliquot basis, in terms of the total amounts of urine and of rinsing water collected.

THE HANDLING OF THE FECES

The feces will be collected once or twice a day and preserved by freezing, drying, or chemical treatment. At the end of each experimental day they must be weighed, mixed, and sampled by the saving of a definite aliquot for analysis; or the whole amount (as with small animals) may be retained.

The feces of cattle or horses can be satisfactorily mixed in a pressed steel wheel-barrow by the use of a mortar hoe. The feces of sheep, swine, and poultry, being much less in quantity, are usually preserved entire until the end of an experimental period.

Aliquot samples are obtained by taking small amounts, at random, from the mass of thoroughly mixed feces. These daily aliquots (or entire portions) may be preserved by freezing alone, in case facilities for the production of very low temperatures are at hand, by refrigeration and thymol, in case the refrigeration facilities are less efficient, or, when no refrigeration is available, by drying or preservation in alcohol.

Satisfactory containers for preservation of feces in cold storage are "Doubletite" or friction-top paint pails, if the material is to be frozen, or screw-cap fruit jars, or specimen jars, if the material is not to be frozen. In case temperatures approaching zero Fahrenheit are not obtainable it is well to supplement refrigeration by the use of thymol. The containers are coated with thymol by rinsing with a ten per cent alcoholic solution, and drying. After the daily aliquot is placed in the container a small amount of powdered thymol is sprinkled over the feces and thoroughly stirred into the mass with a small trowel. The weight of thymol added and the amount of material lost on the trowel must be a negligible percentage of the whole, or must be weighed, and the weight recorded.

After tightly closing the containers they should be properly labeled for storage. Pasted labels usually peel off in cold storage, unless protected by paraffin. Shipping tags tied onto the containers are more satisfactory; and pencil or wax crayon records are much more nearly permanent than ink.

In the preservation of feces by drying samples should be taken in shallow enameled pans, in which they are air-dried at 50°- 60° C. for one week, with daily stirring. They are then exposed to the open air at ordinary temperature for four or five days, weighed, and transferred to tightly closed containers for storage. The containers should be sealed with paraffin, and labeled with shipping tags Pasted labels are often devoured entire, by book-lice.

These air-dried samples are of greatest value for supplementary or emergency use. The principal limitations of their value are the loss of ammonia, and possible mechanical loss, during drying. Rats and mice may also occasion irreparable loss by eating the dried or drying feces, if these materials are not adequately protected.

The feces of small mammals and poultry may be satisfactorily preserved in alcohol, the preservative being driven off by heat as the material is prepared for analysis.

At the end of an experimental period the daily portions (aliquots or entire amounts) are combined for final sampling. Having been weighed they should be subjected to the least possible opportunity for loss of moisture by evaporation, since loss of moisture increases the percentage of solids, and thus increases the apparent elimination of feces. Loss of moisture from feces between times of weighing and analysis has the effect of decreasing positive and increasing negative balances.

In the combining and sampling of the daily aliquots (or entire amounts) these may be mixed with a trowel or hoe, if of proper consistency, or may be prepared for sampling by repeated grinding, preferably in a partially frozen condition, through a power sausage machine. The residues from the inside of the grinder being of thin consistency, must be carefully spread over the main portion, and reincorporated by mixing with a trowel.

All sheet metal containers, such as the friction-top cans and pails, must be resoldered before use, since they are often defective, and a leaky can or pail may affect results disastrously.

THE HANDLING OF MILK

The collection of milk in metabolism investigations is apt to require special measures to avoid loss; thus to prevent some leakage from the udder while the animal is lying down it is usually necessary to milk three or four times during the twenty-four hours. With "easy milkers" it may be necessary, in addition, to seal the teats with flexible collodion after each milking; and the stalls should be wide enough so that in lying down the animal is not obliged to lie upon the udder. To make the collodion adhere it is necessary to wash the milk-fat from the end of the teat with alcohol. It is desirable in the choice of milch cows for metabolism investigations to select individuals which do not milk too freely. With the most careful observance of all precautions it is not easy to collect the milk without some loss.

The amount of milk is most conveniently determined by weight; and throughout the chemical analysis the portions are weighed by difference from a closed flask equipped with rubber stopper and medicine dropper, the portions being removed from the flask by the use of the dropper, which remains with the flask.

In cold storage milk is ordinarily preserved by formalin, the amount of preservative depending upon the length of time the milk is to be kept. One-half or one cubic centimeter of formalin per liter of milk will prevent molding during several months. Potassium permanganate or corrosive sublimate are used in some cases in which they will not interfere with subsequent analysis. Freezing of milk produces physical changes which render sampling very difficult.

After a detailed study of the preservation of milk for analysis, L. S. Palmer[4] makes the following recommendation:

Mix the sample thoroughly as soon as drawn; measure carefully one liter and add between 1.5 and 2.0 cc. of formalin (containing approximately 40 per cent formaldehyde); place a suitable portion in a bottle, preferably a glass-stoppered one, filling the bottle about nine-tenths full; cool at once to 8-10° C. or lower and maintain at that temperature until ready for analysis.

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[4] L. S. Palmer; Mo. Agr. Exp. Sta., Res. Bul. 34 (1919).

GAINS IN WEIGHT AND MILK PRODUCED IN METABOLISM INVESTIGATIONS

The gains in weight of animals maintained under those conditions of restraint which are necessary to the conduct of digestion and metabolism investigations cannot be viewed in the same light as those obtained under the conditions of normal feeding practice.

Likewise the yield of milk is affected by so many factors other than the ration, and the full effects of changes of rations on the quantity of milk produced develop so slowly, that it is impracticable in metabolism investigations with milking cows to derive critical evidence on the milk yield as related to the ration.

3. THE DETERMINATION OF THE TOTAL BALANCE OF MATTER AND ENERGY

H. P. Armsby

A determination of the energy balance of an animal requires in practice a simultaneous determination of at least the principal factors of the balance of matter, while the results on the latter point afford a valuable check upon those regarding energy. It is therefore convenient to consider at the same time the methods used for both purposes. Recognizing the fact that these methods are likely to be of interest to comparatively few investigators, we have not undertaken to describe their details, but simply to outline the general features of the approved methods and to refer the reader to the more important original sources. No attempt at a complete bibliography has been made.

A complete balance experiment involves the determination of the following:

I. The elementary composition and gross energy (heat of combustion) of the feed and the visible excreta (feces, urine, shed hair, etc.)
II. The carbon, hydrogen, and gross energy of the gaseous excreta
III. The oxygen consumed
IV. The heat produced
V. The mechanical work performed

I. The Elementary Composition and Gross Energy of the Visible Excreta

(*a*) *Preparation of samples.*

Carbon and nitrogen may be determined by the ordinary methods of wet combustion as noted under *b*.

For the determination of energy, moist samples must be at least partially dried before being burned, in order to secure complete combustion, while carbon and hydrogen are also frequently determined on dried samples. This drying must be effected without loss of either matter or energy, by decomposition or volatilization, or under conditions which permit as accurate a determination of the losses as possible.

For feeding stuffs, the method of drying in a high vacuum at room temperature seems to offer the greatest security against losses. The drying of urine and feces is a somewhat difficult problem. Braman[6] has studied the drying of the urine of cattle and gives references to earlier work on this subject. Experiments have also been reported by Fürth and Kozitschek,[6] by Higgins and Benedict,[7] and by Emery and Benedict.[8] The possibility of loss in the urine seems to be considerable, particularly with herbivora, in view of the considerable amounts of ammonium salts which the urine of these animals contains. Fortunately, however, the energy of the urine constitutes but a comparatively small fraction of the total amount involved in a balance experiment.

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[6] Jour. Biol. Chem., 19 (1914), 105.

The fact of a loss of nitrogen in the drying of feces is well known, while Fingerling, Köhler, and Reinhardt[9] note similar losses of carbon. The preferable course seems to be to determine the carbon in the fresh samples of both feces and urine in the manner indicated under *b*.

(*b*) *Determination of elementary composition.*

Nitrogen is best determined in fresh samples of both feces and urine, using the ordinary Kjeldahl method for urine, and the König method[10] for the feces. Carbon and hydrogen may be readily determined in air-dry samples of feed by the ordinary methods of ultimate organic analysis, while the determination of carbon may likewise be combined with that of energy by the bomb calorimeter, as has been shown by Fries[11] and by Benedict.[12]

For moist samples, especially feces and urine, the methods of wet combustion may be used for the determination of carbon, thus avoiding losses in drying, and Braman[13] finds that the carbon of moist feces and urine may likewise be determined with accuracy by means of direct combustion, using a quartz tube.

(*c*) *Determination of heats of combustion.*

The method now in most general use is that devised by Berthelot, viz., burning in highly compressed oxygen in a steel bomb. Descriptions of the original and modified forms have been given by Atwater.[14] For details of the method consult Wiley[15] and Fries.[16]

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[6] Biochem. Ztschr., 96, 297.
[7] Amer. Jour. Physiol., 28 (1911), 294.
[8] Amer. Jour. Physiol., 28 (1911), 301.
[9] Landw. Vers. Stat., 84 (1914), 161.
[10] Landw. Vers. Stat. ,38 (1891), 227.
[11] Jour. Amer. Chem. Soc., 31 (1909), 272.
[12] Jour. Amer. Chem. Soc., 32 (1910), 547.
[13] Unpublished.
[14] U. S. Dept. Agr., Office Exp. Sta., Bull. 21 (1895), 121.
[15] Principles and Practice of Agricultural Analysis.
[16] U. S. Dept. Agr., Bur. Anim. Indus., Buls. 94 and 124.

One source of uncertainty in the use of the early form of the bomb calorimeter lies in the necessity of computing the heat losses by radiation. This has subsequently been eliminated by the construction of the various forms of adiabatic calorimeter, which have been described by Richards,[17] Benedict and Higgins,[18] Fries[19] and Riche,[20] and by Holland and Buckley.[21]

The Parr calorimeter, which employs sodium peroxide as an oxidizing agent, has been extensively used for the investigation of fuels, but is apparently less accurate than the form just described. A new and cheaper form of calorimetric bomb has recently been described by Parr.[22]

II. Determination of Gaseous Products

For this purpose some form of respiration apparatus is necessary. In the case of herbivora this must include provision for determining the combustible gases given off. In the case of swine, of carnivora and of man this does not seem to be so essential in view of the small amounts excreted.

Two general types of respiration apparatus are in common use, either being available for the determination of the total gaseous excreta.

(*a*) *The Regnault-Reiset, or closed circuit, apparatus.*—In the closed circuit type of apparatus the animal breathes in a closed chamber or space, the carbon dioxide and water given off being absorbed by proper reagents and the oxygen as used being replenished from a gas holder or a gas cylinder. In the earliest form[23] of this apparatus, which was intended for small animals, the subject was placed under a glass bell jar. Subsequently a larger form was devised for animals as large as sheep. Atwater and Benedict[24] were the first to describe a practicable form of this apparatus for experiments on man, and Zuntz[25] subsequently constructed one for cattle.

A form for the investigation of the pulmonary exchange alone has also been devised by Benedict and is described, along with other forms, by Carpenter.[26]

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[17] Proc. Amer. Acad. Art Sci., 41 (1905), 8.
[18] Jour. Amer. Chem. Soc., 32 (1910), 461.
[19] Jour. Amer. Chem. Soc., 34 (1912), 643.
[20] Jour. Amer. Chem. Soc., 35 (1913), 1747.
[21] Exp. Sta. Rec., 41 (1919), 503.
[22] Jour. Indus. Eng. Chem., 4 (1912), 746.
[23] Ann. de Chem. et de Physique, 3 Series, 26, 299.
[24] Carnegie Institution of Washington, Publication No. 42 (1905).
[25] Landw. Jahrb., 44 (1914), 776.
[26] Carnegie Institution of Washington, Publication No. 216 (1915).

(*b*) *The Pettenkofer, or open circuit, apparatus.*—In this form of apparatus the animal breathes in a continuous measured current of out-door air whose content of water, carbon dioxide, and cumbustible gases is determined on samples taken at the points of entrance and exit. It is the type which has been most commonly used in agricultural research.

The original chamber apparatus was constructed by Pettenkofer[27] at Munich for investigations upon man. Similar ones for cattle were soon afterwards installed at Salzmünde and at Göttingen and others later at Möckern and Leipzig. A form for the investigation of pulmonary respiration was likewise devised by Zuntz and Geppert. This form of apparatus was used by Zuntz[28] in his extensive investigations upon the working horse, and Hagemann[29] has also applied it to sheep. The principle of the Pettenkofer apparatus is also involved in the construction of the respiration calorimeter of Armsby and Fries, for work with cattle.

III. THE DETERMINATION OF OXYGEN CONSUMED

The determination of the oxygen consumed may be combined with that of the gaseous excreta by the respiration apparatus, although with considerable difficulties in practice.

(*a*) *Determination with the closed circuit apparatus.*—This requires, in addition to the determination of the amount of oxygen admitted to the apparatus, a determination of the amount contained in the apparatus at the beginning and at the end of an experiment. With a chamber apparatus, the latter is a decidedly difficult task. In the pulmonary form the problem is less difficult.

(*b*) *Determination with the open circuit apparatus.*—With the pulmonary form of apparatus it is not difficult to determine the deficit of oxygen in the expired air with a good degree of accuracy.

The chamber apparatus is commonly used only for the determination of the expired gases. It is possible, however, to utilize it also for determining the amount of oxygen consumed by the animal, the difficulty lying only in the extremely accurate determinations of oxygen in the outgoing air which are necessary. Jacquet[30] has used the method for small animals while Møllgaard and Anderson, and Fries[31] have also applied it to cattle.

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[27] Ann. Chem. Pharm., Suppl. Bd. II, p. 1. Compare also Atwater—U. S. Dept. Agr., Office of Exp. Stas., Bul. 21 (1895), 106.

[28] Landw. Jahrb., 18 (1889); 27 Ergzbdl. (1898).

[29] Arch. (Anat. u.) Physiol., 1899, Supp., p. 138.

[30] Verhandl. der Basler natur. Ges., 15 (1903).

[31] Amer. Jour. Physiol., 55 (1921), 53.

IV. DETERMINATION OF HEAT PRODUCED

(*a*) *Direct calorimetry.*—The actual determination of the heat produced by an animal requires, of course, the use of some form of calorimeter. Moreover, since provision must be made for ventilation and for the determination for the gaseous products given off, the apparatus must be also a respiration apparatus either of the closed or open circuit type.

For a general classification of respiration calorimeters and a description of some common forms including the open-circuit flow-calorimeter of Armsby and Fries, consult "The Nutrition of Farm Animals," pages 235-240. A very complete description of all but the latest form is given by Lefevre.[32]

(*b*) *Indirect calorimetry.*—For many purposes, the heat production may be computed with sufficient accuracy from the results of respiration experiments. When the carbon dioxide excreted and the oxygen consumed are determined, the respiratory quotient in carnivora or omnivora, together with a determination of the urinary nitrogen, affords pretty definite information as to the proportions of fats, carbohydrates and proteins katabolized, the quotient for fat being 0.7, for carbohydrates 1.0, and for protein about 0.8. From this it is easy to compute the calorific equivalent of a unit of carbon or of oxygen. As Fries[33] has recently shown, this method is not directly applicable to herbivora, but Anderson[34] has devised an ingenious modification of the method by which it is possible to compute the heat production from the urinary nitrogen and the amounts of carbon dioxide and methane excreted and oxygen consumed, while Armsby, Fries, and Braman[35] have recently reported data on the calorific equivalent of the total carbon dioxide excretion of cattle which promise to be useful.

A second method of indirect calorimetry is based on the determination of the complete balance of matter and of the energy contained in feed, feces, urine, and combustible gases. This is the method used by Kellner[36] in his early investigations upon the energy metabolism of cattle, and in numerous subsequent ones.

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[32] Chaleur Animale et Bioenergétique: Masson et Cie., Paris, 1911, 77-228.

[33] Amer. Jour. Physiol., 55 (1921), 53.

[34] Den. Kgl. Veterinaer-og Landbohøjskole, Copenhagen: Aarsskrift, 1920.

[35] Proc. Nat'l Acad. of Sci., 6 (1920), 263.

[36] Landw Vers Stat. 47 (1896), 275.

V. THE DETERMINATION OF MECHANICAL WORK

In experiments on man, various forms of mechanical work such as climbing a stair-case, lifting a weight, or riding a bicycle have been investigated. With animals substantially only two methods have been used. In one of these the animal performs work with a sweep power, which also serves as a dynamometer. This form was used by Wolff[37] and by Grandeau and Le Clerc[38] in studying the feed requirements of the working horse.

The second form of apparatus is the tread power, in which the animal does work by lifting its own weight. This is the form used by Zuntz in connection with the Zuntz-Geppert form of respiration apparatus (See II, *b*) in his extensive investigations upon the metabolism of the working horse, while Benedict and Murschhauser[39] and others have applied it to man.

Any work performed in the chamber of a respiration calorimeter is, of course, converted into heat and measured along with that arising from other physiological processes.

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[37] Landw. Vers. Sta., 21 (1878), 19; Landw. Jahrb., 24 (1895), 190-193.
[38] Ann. Sci. Agron., 1881, 1, 464.
[39] Carnegie Institution of Washington, Publication No. 231 (1915).

4. FEEDING EXPERIMENTS

The so-called feeding experiment is usually a relatively simple procedure involving an extended period of observation, the experimental subjects commonly being maintained under approximately normal conditions, and the results usually being of the nature of records on growth, reproduction, or other animal increase.

The method of the feeding experiment often differs from that of practical feeding operations only in refinement and elaboration. Through such comparatively simple procedures a great diversity of problems, superficial or abstruse, directly practical, purely physiological, or otherwise, may be investigated.

Feeding experiments may determine either the net result of a normal complication of factors, or the specific effect of individual factors. In view of the indefinite diversity of objects which may be sought, and of details of experimental methods, it is not our purpose to attempt to standardize the entire field of operation, but merely to record a few principles of general significance.

THE PLANNING OF FEEDING EXPERIMENTS

In the planning of feeding experiments thought must be given the consideration of relation of conditions of experimentation to conditions of practice, in order that the results of the experiment may be due to the same conditions as determine the results in practice, and, therefore, truly applicable to practice. This principle, though stated in a few words, is worthy of most extended and painstaking recognition in feeding experimentation.

Special efforts may be necessary to reduce the problem to the simple terms essential to clarity of results; thus, the market grade of meat animals is the resultant of a great complication of varying factors, which for satisfactory experimental treatment must be resolved into individual components.

Uncontrolled conditions, so far as practicable, should be made the subject of definite record; and all other conditions of significance, especially the details of experimental methods, should be made matters of record, in order to permit of judicial appraisal of conclusions, and repetition of experiments.

The effects of variations in soil and season on the amount and composition of the growth of forage crops, and effects of the method of harvesting and of amount of exposure to sunlight during curing, on the food value of the same, are sufficiently pronounced so that experiments involving the use of such feeds should be planned in the light of these facts.

This applies especially to experiments in which a forage crop is related to the area upon which it was produced. Such work must cope with all of the compromising conditions inherent in soil fertility investigations, and can be rendered tolerably accurate only by the exercise of the greatest care, and by repetition much more frequent than is necessary in most types of feeding experimentation.

The plan of experiment should, if practicable, provide a basis for comparisons within the experiment, and also between the experiment and other such, conducted at earlier dates, or to be conducted later, by the inclusion of check lots on standard rations. Such a practice, carried through an extensive program of research, adds greatly to its value.

It seems likely that an investigation of the effect of the weather on the results of feeding experiments, especially on the live weights of animals, will show that weather conditions should be made a matter of record in connection with exacting experiments in which live weights are significant. Of importance in this connection is the effect of weather on the drinking and retention of water.

This matter has received some consideration in the following publications:

Vermont Agr. Exp. Sta., Rpt., 1891, 65, 87, 88; 1892, 16, 128; 1893, 88-92.

Arizona Agr. Exp. Sta., Rpt., 1901, 327-332.

Indiana Agr. Exp. Sta., Bul. 47.

Much improvement in feeding experimentation awaits the more general employment of the methods of histology in the experimental program. By this means there will doubtless be revealed results of much interest and significance, as indicating the conditions of life of the cells of the various tissues, and of a delicacy far beyond the possibility of detection by chemical analysis, which must first destroy, before it identifies and evaluates the wreckage.

As to the scope of a particular experiment—the value of the results depends largely upon the plan being limited in extent to correspond with the number of experimental animals involved; so as to make possible the derivation of a certain amount of evidence of positive significance, rather than data warranting only the inconclusive discussion of a more extensive field.

PRELIMINARY FEEDING

In feed comparisons there should be a preliminary period, before the taking of initial experimental weights, of sufficient length to permit of the complete stabilization of live weights as affected by the content of the alimentary tract.

In experiments of such nature that the record of the "fill" taking place during the period of adaptation to the ration is one of the results sought for, the data from this preliminary period should be recorded separately in such manner as not to contribute an element of error in relation to feed consumed per unit of increase during the main part of the experiment. The apparent gain in weight of animals on experiment must be real gain in the sense of not involving an increase in proportion of "fill."

THE LENGTH OF FEEDING EXPERIMENTS

In the more carefully considered work there is a marked tendency to increase the length of experiments to cover the whole of the life process of interest, and to record the rate and character of response of the subjects to the treatment, by regular periodical observations throughout the course of the experiment.

Nutrition experiments of short duration, even when accompanied by elaborate chemical and physiological analyses and examinations, give but imperfect insight into the final nutritive value of a feed, ration, or isolated nutrient for long-continued, normal, and healthy growth. Experiments having such objects, then, should cover the entire life cycle.

Great loss and confusion have resulted from the drawing of conclusions from investigations lacking in proper duration.

NUMBERS OF EXPERIMENTAL SUBJECTS

In feeding experiments, where the results are of the nature of gains in live weight, much larger numbers of individuals are required than in experiments for the measurement of less complex processes than growth. Based upon the average coefficients of variation found for sheep, steers, and swine, calculation indicates that experimental lots should contain at least 10 to 14 animals, or even 25 to 30 animals when the rations or other conditions under investigation are very similar. The necessity of using at least 10 to 15 animals per lot in feeding trials seems to be well established. If this number can be increasd, all the better.

Again, however, it is well to note that increasing the size of lots is no remedy for a poor selection of experimental animals. Furthermore, increasing the size of lots cannot eliminate individuality, but merely reduces its effects on the average. It has been shown that when there are as many as 40 animals to the lot, an appreciable degree of uncertainty still attaches to average lot gains. Also it should be borne in mind that the beneficial effect of increasing the size of lots varies not with the number in the lot, but with the square root of this number. Thus, for the same standard deviation of individual gains, a lot of 10 animals will give a probable error of the average gain only twice as large as a lot of 40 animals.

It has not yet been proved that the probable error of results of feeding animals can be reduced by preliminary functional tests. This subject needs further study. For the present the safest means of reducing experimental error is through numbers of carefully selected subjects, and through repetition of trials.

INDIVIDUAL, GROUP, AND SELF-FEEDING

Individual feeding.—Individual feeding is essential in many experiments, and is desirable in a still larger class of investigations, since this method of procedure tends toward accuracy of results, through differentiation of individual data, without which their proper criticism is impossible; and through favoring uniformity in the consumption of food, and in production, since these are conducive to mathematically sound conclusions.

Even where individual feeding is not followed in the practical operation to which the results are to be applied, this method of feeding may be, and usually is, none the less desirable in experimental work, as a means of assuring accurate measurement of the phenomena under investigation. Where the effects of jostling and competition at the feed trough constitute an essential factor in the problem under investigation these effects must not be eliminated by individual feeding, but in all cases where accurate comparisons of feeds, or other factors of fundamental significance are the desiderata, the experimental subjects should be fed individually.

Group feeding.—Controlled group feeding (the usual method in practice) is satisfactory in investigations of the sort most directly applying to the same process in practice. The chief merit of this system in experimental work is economy of labor, and of expense in the provision of equipment.

The principal limitations of this method are that the results are essentially averages of unknown individual data, the significance and validity of which cannot be directly considered; further, as a practical measure in the conduct of feeding experiments, individual data are of very great value as providing the means for eliminating an individual animal at any time at which such a measure may become desirable; individual data, therefore, tend to protect the investigation from compromise or ruin through the effects of accident, disease, or preexistent but undetected abnormality of experimental subjects.

Self-feeding.—Unrestricted allowance of feed may be practiced on either the group or the individual basis. This method of feeding has a wide range of usefulness in investigation work. Where the class of animals serving as subjects can be satisfactorily handled by self-feeding this method commends itself, especially for investigations in which maximum production is desired, or where we wish to allow unrestricted expression of appetite and preference. By proper feeding devices the prevention of waste and the measurement of feed consumption may be satisfactorily accomplished with certain types of rations and kinds of animals. Under other conditions this method is not practicable. It is not readily usable in investigations requiring uniformity of consumption, or the most accurate chemical accounting for feeds consumed, on a laboratory basis.

LIVE WEIGHTS

Initial and final live weights may be taken on three or more consecutive days, the average weight being considered as the weight on the middle day.

Periodic weights should also be taken, throughout an experiment, to provide a basis for the plotting of curves showing the course of gains of the lots or individuals to be compared, and for corrections on account of the removal of any individual in case of accident.

Some experimenters withhold water from experimental subjects from night until an early morning weighing, in order to minimize the individual variation due to water drunk. This is in recognition of the fact that a single drink of water, with an animal like a cow, may weigh as much as the real increase in live weight during many days, or even a few weeks. It is a fact, however, that this procedure does not entirely eliminate extensive variation in the weight of cattle, and under some conditions of weather, weighing facilities, etc., it may be definitely inadvisable to withhold water during the night previous to an experimental weighing.

The variability of the live weights of cattle constitutes a vexatious and baffling problem which is fully appreciated only as abundant data are obtained. Fairly consistent weights on certain individuals are obtainable, however, in experiments in which they are watered separately, at regular intervals.

"Shrunk" weights, like dockage, commission, and freight, are ordinarily relevant only in commercial procedure and accounts.

Recording Amounts of Feed Consumed

The amounts of feed consumed must be recorded in all cases.

It would seem to be unnecessary to mention so obvious a requirement of experimental procedure, but a great mass of results of feeding experiments with small animals, minus data on amounts of feeds consumed, have been given space in reputable scientific journals. In much of this work the adequacy of the ration, and the relative content of rations in undetermined constituents, is estimated by the growth, condition, and performance of the subjects *without regard to the amounts of feed used to produce* these effects. Largely upon such an imperfect basis has been established a voluminous literature in a new and peculiarly difficult field of research, in which there is every demand for the most perfect experimental method.

In our opinion this practice would be defensible only on condition of its being definitely established, with the particular feeds and species of animals involved, either that the amount of feed consumed is not affected by its kind, so that all subjects compared would have eaten the same amount, or that the palatability of the ration reflects its nutritive value in an accurately quantitative manner, so that in case animals eat more of one ration than of another this greater amount accurately represents its greater efficiency, the one hypothesis being as absurd as the other.

It is of course a fact that animals *tend* to eat their fill, and that they commonly eat larger quantities of efficient rations than of less efficient ones; but that these conditions are true in any such accurate and unvarying way as to warrant neglect to provide facilities necessary to the quantitative accounting for the feed, and neglect to consider the amount consumed, in the formulation of conclusions, is unthinkable.

Even with time involved as a matter of record, and with complete data as to performance through life cycles at hand, it is still necessary to know the amounts of feed eaten, in order to permit of feed comparisons.

dates it is important to have records of the condition of the experimental subjects at those times.

Such periodic observations may be made with photographs, either informal or with the subject posed before a ruled screen, by measurements, by evaluation by market experts, or by the slaughter of representative groups or individuals.

Photography may yield striking results, of unsurpassed significance; and efforts to exhibit the results of experiments by this method may be profitable.

Evaluations by market experts may be of value, but in as much as they are at best only expressions of judgment, and not in any sense actual measures of value, they cannot be regarded as scientific data, and should not be treated as such.

The slaughter of representative groups or individuals, at intervals, yields evidence of the highest value, but the practicability of this procedure may be limited by the numbers of subjects involved.

TERMINATION OF FEEDING EXPERIMENTS

Feeding experiments may be terminated either at a definite, uniform weight of subjects (individual or group basis), without regard to the time required for the several lots of individuals to reach this fixed goal, or at a single, fixed time, without regard to the weights attained by the experimental subjects.

Since time as well as feed represents actual expense, and since age, as well as weight attained, is a matter of physiological significance, both of these methods of terminating feeding experiments yield valuable results.

In experiments directed especially toward immediate financial ends it is important to feed to a definite average weight per lot, but this may be impracticable in experiments to be terminated by an elaborate program of accounting for the bodies of the subjects, because of practical difficulties due to the uncertain time at which the work connected with the termination of the experiment must be done, and the manifold increase in the labor and expenses involved.

Also, in experiments in which the nutritive value of feeds is compared in a critical way, it is as important that the subjects be of the same age at the end as at the beginning; and with many rations it is quite impracticable, on account of inherent nutritive limitations, to bring all lots to the same weight.

GRAPHIC PRESENTATION OF RESULTS OF FEEDING EXPERIMENTS

The graphic presentation of results, especially by the use of plotted curves, indicating time and amount and direction of change in the experimental subjects, are much more readily understandable than are tables of numerical results, and should be used where the number of intermediate observations makes possible this method of presentation; indeed the requirements of this method may well be considered, in determining the number of intermediate observations to be taken.

After the determination of normal curves of growth, these may be made the basis for comparison of rate of increase as affected by breed, individuality or ration.[40]

This method of exhibiting results may also be used to advantage in determining the amount in which a particular supplement should be fed with a basal ration. The experimental subjects should first be brought into a uniform rate or economy of gain on the basal ration. The supplement should then be introduced, in small proportion, and continued thus until the full improvement due to the addition has been realized. Subsequent additions of the supplement should be made, in the same amount and at regular intervals, until no further improvement in the rate or economy of gain (whichever is the basis of the exhibit) results therefrom. Then by slight variations above and below the apparent optimum this point can be definitely located.

In researches on milk production the normal rate of decrease of lactation should be considered in judging of the effects of feeds. Curves of normal milk production should be derived for each breed of animals used for milk production.

Examples of successful use of graphic methods of presentation of results of feeding experiments may be seen in the work of P. F. Trowbridge, C. R. Moulton and associates,[41] and in the article on Skim Milk and Milk Substitutes for Calf Feeding, by R. E. Caldwell.[42] C. C. Hayden has used the same principles as did Caldwell, but instead of photographing an animal in front of a metrically ruled sheet or chart, has photographed it behind a metric wire screen.

Graphic methods in the presentation of the financial outcome of feeding experiments have been used to advantage by H. H. Mitchell.[43]

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[40] See Mo. Agr. Exp. Sta., Res. Buls. 36, 43 and a later bulletin, in press, on Normal Growth of Farm Animals.

[41] Mo. Agr. Exp. Sta., Res. Buls. 28, 30, 38, 43, 54 and 55.

[42] Proc. Amer. Soc. Animal Prod. (1915-16), 21.

[43] Proc. Amer. Soc. Animal Prod. (1921), 96.

THE CONDUCT OF SLAUGHTER TESTS

In preparing for the chemical accounting for carcasses, organs, and tissues of animals, all requirements must be provided for in advance, in order that the program may proceed in prompt and orderly fashion, without delay in the handling of the perishable products.

The most important considerations in this connection are (1) convenient facilities for fast work, (2) maintenance of the identity of parts and products by a positive system of labeling, (3) prevention of loss of weight through evaporation (or its accurate quantitative determination), (4) prevention of chemical change through enzyme action, and (5) prevention of the extensive translocation of moisture and dissolved substances which takes place within an animal body, between its liquids, tissues, and organs, after death.

Suggestive details of procedure in the slaughtering of a steer are given by Trowbridge, Moulton, and Haigh.[44]

A well planned experimental slaughter equipment is of great service through making it possible for the operatives to give their attention to the more scientific aspects of the work.

All possible provisions should be made for concentration upon the task at hand; otherwise one may become swamped in confusion. The whole procedure must be reduced to a routine, with each and every part provided for in advance by definite assignment to some one of the workers, so that the entire program may proceed mechanically, on a carefully predetermined plan. Tools must be sharp; forms must be provided for the convenient recording of weights and measures; weighed, numbered, and labeled tight-closing receptacles must be provided for all parts to be separately handled; visitors should be excluded; and if the parts and organs are to be subjected to examination, during the killing process, as by a pathologist, or sampled, as by a histologist, this work must be provided for as a definite part of the routine, to prevent confusion, delay, and loss of identity of parts.

The complete accounting for the blood is facilitated by the provision of closed receptacles, weighed containing absorbent cloths. A rubber scraper and dustpan are helpful in the recovery of blood from the floor.

Friction-top pails or cans, for parts to be retained, are useful in preventing loss of moisture. These should be resoldered when purchased, in order to prevent the occasional loss of liquid which otherwise is apt to occur.

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[44] Mo. Agr. Exp. Sta., Res. Buls. 28, 30, 54.

All weights and measures which cannot be later checked should be read by two persons. It is also important that net weights be calculated and summations made as promptly as possible in order to facilitate the detection and correction of possible errors.

It is important that tissues be not frozen previous to sampling for analysis, because of the separation of the liquids from the solids, which is caused by freezing, and the consequent increased difficulty of sampling, and increased liability to spoilage.

Power grinders should be provided for the preparation of tissues for sampling.

Small amounts of ground tissue may be mixed in a porcelain dish, or in an enameled pan, or on an aluminum-topped table. For larger quantities a mechanical meat mixer is useful, because of the ease and rapidity with which a thorough mixture can be obtained.

The Enterprise meat chopper is the most useful machine for the sampling of miscellaneous materials of firm consistency.

For finer cutting, or for the sampling of either very soft or very tough materials, use a "meat flyer" of the "Buffalo" type. This machine cuts skin very successfully, especially if partially frozen. It is handled by butcher's supply houses.

The first grinding of the fresh skeleton can be accomplished in a Mann bone cutter, or a poultry bone grinder, or a Central Scientific Company mill No. 3520.

The final grinding of partially or completely dried and extracted bone can be accomplished in a Krupp mill of the Excelsior type, or in the mill of the Central Scientific Company, as above specified. The Krupp mill is handled by laboratory supply houses.

The most rapid and thorough sampling of a large quantity of meat is accomplished by running the whole once through a power-driven Enterprise mill, mixing the whole in a mechanical meat mixer, and then cutting a large sample (full capacity) in a Buffalo meat cutter. The samples for analysis are taken from the rotating bowl of this machine.

Tendon can be cut with a Buffalo "meat flyer," or with an Abbé cutter.

Hair may be ground with the skin, in the Buffalo meat cutter, or, if sampled separately, may be ground in an Abbé cutter (Abbé Engineering Company of New York City). Small samples of hog hair may be put through a hand-power Enterprise meat-chopper, using the ridged plate provided for making nut butter.

Hoofs and horns may be handled in a poultry bone mill, or in a Central Scientific Company mill No. 3520. We have ground them, after softening in an autoclave, in a hand-power, Enterprise meat-chopper. If thus treated by steam, previous to grinding, the change in moisture content should be recorded by weights before and after treatment. The final grinding of hoof and horn may be accomplished in a Krupp Excelsior mill.

Ground animal tissues tend to spoil quickly, and should, therefore, be frozen up promptly in friction-top cans or pails. The freezing of finely-ground tissues, containing much moisture, in glass jars, breaks the containers.

A point of importance in the sampling of refractory materials of animal origin is that they be not subjected to so much handling and exposure to the air as to result in significant loss of moisture.

For parts into which a beef animal, or a hog, should be divided, for chemical analysis, see the Reports of the Committee on Terminology, Proceedings of the American Society of Animal Production for 1910 and for 1914.

MILK PRODUCTION

Methods of experimentation in relation to milk production have been made the subject of a critical study by L. A. Maynard and W. I. Myers.[45] Since the whole of this bulletin is relevant to our discussion it is our judgment that we cannot do better than to refrain from attempt at condensation, and to refer the student to the original.

STATEMENTS OF FINANCIAL RESULTS OF FEEDING EXPERIMENTS

The financial outcome of investigations in the field of animal production depends upon a number of factors, prominent among which are (1) the cost of the animal, (2) the cost of the feed, (3) the cost of the man labor, and horse labor, (4) the cost of the use of the land and equipment, (5) the cost of marketing, (6) the selling price of the product, (7) the value of the by-products, and (8) the purchasing value of the unit of exchange.

A consistent statement of the economic aspects of such operations would include all contributing factors expressed in terms of a constant measure of value. Since there is in existence no such unvarying measure, however, there is no basis for the logical statement of financial results; and since the factors which determine these results are not under experimental control, but vary in ways which cannot be foretold, we should regard the financial statement of a feeding experiment as an incidental matter without essential relation to the fundamental scientific results of the investigation.

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[45] Cornell Univ. Agr. Exp. Sta., Bul. 397 (1918).

The dollar is no more a fixed standard, and therefore a real measure, in the field of economics, than it is in the field of physiology.

The farmer, naturally, depends largely upon a statement in terms of the prevailing medium of exchange. He accepts the dollar as it is, makes the necessary mental allowance for its value at the time, and virtually demands a statement of the financial outcome of feeding experiments, especially in investigations of operations the results of which are not conveniently reducible to more concrete terms. In so doing he has frequently in mind (1) the complex of market conditions confronting the industry at the time, (2) the outcome of his own methods of meeting this particular situation, and (3) a desire to compare his methods and results with those of the experimenter.

In view of all these facts the investigator should make every effort to state his results in concrete terms, as in per cent of increase or decrease of feed expenditure, in pounds of product per acre of land involved, in pounds of feed, or in replacement value of pounds of one feed by pounds of another. It is also highly desirable in all extensive programs of feeding research to adopt, at the beginning, a standard ration, to be used throughout the investigation as a measure for other rations.

Statements of financial outcome based upon graduated levels of cost are of value in some simple considerations, but have no wide usefulness since the several factors do not always vary in the same direction, or nearly enough at the same rate to warrant elaborate statements of outcome based upon a graduated scale of costs.

In the publication of results of feeding experiments the scientific conclusions and the financial statement should be treated separately, with the latter in relative brevity and in proper subordination, thus guarding against the possibility of loss of emphasis from the fundamental results through confusion with the financial outcome.

The wide fluctuations of the live-stock market, in relative cost of feeders and fat animals, and of animals of different weights, grades, and degrees of fatness, are familiar and typical instances of the kind of conditions which render unreliable and scientifically irrelevant the financial outcome as a measure of the results of feeding experiments.

From this point of view the evaluations of animals, by market experts, at intervals during an investigation, are of limited value. A more significant procedure is to trace the progress of the investigation by the slaughter, at intervals, of representative individuals or groups, with the recording of such weights and other observations as to fatness, etc., as are deemed pertinent to the study.

A simple, ingenious, and valuable graphic method of presentation of the financial phases of feeding experiments was devised by H. H. Mitchell, and published as Illinois Agr. Exp. Sta. Bul. 234; see also Proc. Amer. Soc. Animal Prod., 1921, 93-97.

5. REFERENCES TO LITERATURE ON METHODS AND EQUIPMENT

We submit, below, a brief list of references to some of the more readily available descriptions and illustrations relating to methods and equipment for the conduct of experiments in the field of animal production. This list is not exhaustive; in fact it might be very greatly extended, but will be found at least suggestive.

An exhaustive, monographic presentation of this subject is Robert Tigerstedt's three-volume Handbuch der physiologischen Methodik, Leipzig, 1911. Part 3 of Volume I, devoted to the subject of methods of experimentation in nutrition, is indispensable to the critical student in this field. Illustrated with 137 figures, it covers the whole field of metabolic research, with farm animals, laboratory animals, human beings, and even fishes. The European literature is fully treated, but very few American articles are cited.

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An aluminum collection receptacle for digestion experiments with poultry was devised by E. W. Brown (Bur. An. Ind., Bul. 56) and a rubber pouch was used, at a later date, by Bartlett (Maine Agr. Exp. Sta., Bul. 184). A metabolism crate, so constructed as to permit of easy cleaning, with removable false bottom of wire screen and collection pan of galvanized iron can be readily devised.

Respiration Chamber

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Mice, Cages for

Helen S. Mitchell; Jour. Lab. and Clin. Med. 7 (1922), No. 5.

J. A. Long; Anatomical Record 2 (1916), 103.

Rabbits, Cages for

Dr. R. H. Carr writes that for rabbits he uses a cage based on a 3′ 0″ x 6′ 0″ shallow pan, with false bottom of ½″ mesh wire 1″ above floor of pan. Covering both screen and pan is a cage 18″ high of 1″ mesh screen. There are two 5″ openings in this screen, to permit access to feed and water.

Pigeons, Cages for

From Dr. Oscar Riddle we have the suggestion that the size of the cage used for experimental work with pigeons is a "matter of very great importance" inasmuch as close confinement has been shown, in unpublished work by Dr. Honeywell and himself, to decrease the blood sugar from a value of 180 mg. per 100 c. c. of blood to 125 mg., doubtless signifying an abnormally reduced metabolism.

Dr. R. H. Carr writes that for pigeons he uses a collapsible wire cage, 3′ 0″ x 3′ 0″ x 3′ 6″ high, with false bottom of ¾″ mesh screen 1″ above floor of cage. There is a 6″ x 10″ sliding door, to permit entrance of the bird, and two openings at the side of the cage, for the attachment of feed and water receptacles.

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BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

CAUSES OF GEOGRAPHICAL VARIATIONS IN THE INFLUENZA EPIDEMIC OF 1918 IN THE CITIES OF THE UNITED STATES

REPORT OF THE COMMITTEE ON THE ATMOSPHERE AND MAN,* OF THE NATIONAL RESEARCH COUNCIL

PRESENTED BY ELLSWORTH HUNTINGTON, CHAIRMAN

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*The Committee on the Atmosphere and Man is a joint committee of the Divisions of Biology and Agriculture and of Medical Sciences. The present report was prepared by a Subcommittee on the Atmosphere and Mortality consisting of the following members: Ellsworth Huntington, Yale University, Chairman; Louis I. Dublin, Metropolitan Life Insurance Company, New York City; J. Arthur Harris, Station for Experimental Evolution, Cold Spring Harbor, L. I., N. Y.; Frederick L. Hoffman, Prudential Life Insurance Company, Newark, New Jersey; Arthur Hunter, New York Life Insurance Company, New York City; G. T. Palmer, Board of Health, Detroit, Michigan; Raymond Pearl, Johns Hopkins University, Baltimore, Maryland.

CAUSES OF GEOGRAPHICAL VARIATIONS IN THE INFLUENZA EPIDEMIC OF 1918 IN CITIES OF THE UNITED STATES*

THE PROBLEM

Even before the great influenza epidemic of 1918 far-sighted men like Sir Ronald Ross raised the question whether influenza may ultimately harm northern countries as much as malaria and hookworm harm those of low latitudes. Recent events give new ground for this fear. Not only was the influenza epidemic of 1918 the most calamitous event for many generations, aside from the Great War, but the minor epidemics which have succeeded it are still a menace.

The investigator of influenza is confronted by the important question of why epidemics occur with such virulence not only at certain times, but at certain places. The months of October and November, 1918, were a time of extraordinary activity among the bacteria which cause influenza, and also a time when the destructiveness of the bacteria varied enormously from city to city. For instance, among the large cities of the United States the death rate from the epidemic during its first ten weeks was only a fourth as great in Milwaukee as in Philadelphia. (See Table XII.) Even in cities as near together and as similar as Pittsburgh and Toledo, the excess in the death rate because of the epidemic, from September, 1918, to June, 1919, was three times as great in the river city as in the lake city. Among the possible explanations of these extraordinary phenomena four may be mentioned: (1) Both the bacteria and the human organism may be subject to certain inherent physiological rhythms which cause vigor at some times and in some places, and weakness at other times and in other places. If the bacteria are vigorous when the human organism is weak an unusually severe epidemic may result regardless of the environment. (2) It is equally possible that the bacteria and the human organism are subject to rhythms and variations because of their environment. (3) There may be both kinds of rhythms, physiological and environmental, and these may occur in both the human and the bacterial organism. A combination of physiological weakness in man, physiological strength in the bacteria, unfavorable environment for man, and favorable environment for the bacteria, if such a combination is possible, might account for the extraordinary virulence of the epidemic of 1918. (4) Bacteria of one kind may influence those of another kind in such a way that the accidental combination of the two at some special phase of their activity may induce great virulence.

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*This investigation was financed by the Equitable Life Assurance Society of New York City whose cooperation is gratefully acknowledged.

Regardless of whether one of these possibilities or some other is the actual case, it is clear that one of the first problems to be solved is to determine how far the virulence of the disease varies in harmony with environmental conditions. When this has been done, it will be possible to scrutinize the remaining variations of the disease and determine how far they depend upon purely physiological conditions. The reverse is also possible, namely, to investigate the physiological conditions both of man and of the disease-bearing bacteria, and then to study the remaining non-physiological variations in respect to environment. The present paper is limited to the first method and discusses only environmental effects. It is also limited to the main epidemic of 1918 in the United States, and its conclusions apply only to that occurrence. Furthermore, the present study is confined entirely to the problem of why the virulence of the epidemic varied from place to place, and does not touch the problem of the causes of the epidemic and the reasons why it broke out at a certain time. A similar study of other epidemics and other regions is urgently needed, but must be postponed until funds are available for the prolonged tabulations and calculations demanded by this sort of work.

THE METHOD

Numerous attempts have been made to produce influenza in human beings by pure cultures of various organisms isolated from this condition, by nasal secretions from cases, and by intimate contact experiments between volunteers and cases of the disease.* These experiments, although well controlled in many instances and comprising a considerable number of individuals, have so far shed little or no light on the etiological agent of the disease or the secondary factors influencing its transmission. It is possible, however, to employ a statistical method which gives to nature's terrible experiment of 1918 almost the exactness of an experiment in the laboratory. This method is thus set forth by Pearl* in the second of his influenza studies.

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*"Some Experiments on the Transmission of Influenza," H. R. Wahl, G. B. White, and H. W. Lyall, Journal of Infectious Diseases, 1919, XXV, No. 5, p. 419.

Friedberger, Med. Verein Greifswald, Aug. 11, 1918.

"Experiments Upon Volunteers to Determine the Cause and Mode of Spread of Influenza, Boston, Nov. and Dec., 1918," M. J. Rosenau, W. J. Keegan, Joseph Goldberger, and G. C. Lake, Hygienic Laboratory Bulletin No. 123, Feb., 1921.

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"Experiments Upon Volunteers to Determine the Cause and Mode of Spread of Influenza, Boston, Feb. and March, 1919," M. J. Rosenau, W. J. Keegan, De Wayne Richey, G. W. McCoy, Joseph Goldberger, J. P. Leake, and G. C. Lake, Hygienic Laboratory Bulletin, No. 123, Feb., 1921.

"The most useful general method of acquiring knowledge of dynamic phenomena is unquestionably the experimental method. When we deal with phenomena of human biology, there is a wide range of matters in which the laboratory experimental method is, in the nature of the case, ruled out. Unfortunately, one cannot breed homozygous strains of men at will for experimental purposes, nor subject them methodically to desired environmental conditions. In studying most problems of human biology resort must be had to some form of the statistical method. This is fundamentally a descriptive method, and hence in many of its phases is ill-adapted to the analysis of dynamically active events. There is, however, one branch of the statistical calculus which offers certain methodological possibilities which I think have been generally overlooked. Let us consider this.

"The essence of the experimental method, as practiced in the laboratory, and in theory, is that, of the multitude of variables conditioning a phenomenon, as many as possible are, by appropriate methods, held constant while one variable (or at most a very few selected variables) is allowed to vary and the results are noted. One may then deduce the relative significance of the selected variable in determining the phenomenon under observation. Now we frequently hear in scientific discussions about the experiments that Nature makes. Actually the true conditions of an experiment are rarely if ever realized in the course of natural events. It is just because Nature permits manifold and haphazard changes in *all* variables at the same time that recourse must be had to the method of experimental control in the laboratory. What is needed in order to interpret the results, in the experimental sense, and determine the meaning of the manifold and ceaseless changes and variations in the flow of naturally determined events, is some method of picking out of the manifold some selected *constant* conditions of a series of variables, and then measuring the extent and character of the variations in a *single* selected variable, whose true relative influence upon the phenomenon it is desired to know, while all these other variables are held constant. If this can be done we shall have realized all the epistemological advantages of the experimental method as practiced in the laboratory, and have freed ourselves at the same time from the limitations which in so many cases inhere in the material itself and make the laboratory type of experimental inquiry impossible. In other words, we shall have let Nature perform the experiment, in the sense of determining the phenomena, in her own way, while we evaluate the results in critically analytical terms of precisely the same sort and meaning as those in which we evaluate the results of a laboratory experiment.

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*Raymond Pearl; Influenza Studies, Reprint No. 642, Public Health Reports. U. S. Public Health Service, 1921.

"Now exactly this epistemological boon is actually afforded in the method of partial or net correlation, if properly handled. This analytically simple, if geometrically complex, calculus enables one, out of a manifold complex of variables operating in an entirely uncontrolled and natural manner, to determine the variation of any selected single variable, or the correlation of any selected pair for *constant* conditions or values of the other variables in the complex. I judge that the epistemological possibilities of this method are not yet fully grasped by scientific men generally. When they are I believe it will rank as a fundamental method of acquiring knowledge, combining certain of the advantages of the descriptive or historical and of the experimental methods. It seems to me much more effectively to justify Royce's eulogy of the statistical method than any of the arguments which he advanced. The best elementary, but at the same time adequate, account of the method is that of Yule."

The method of partial or net correlation may be illustrated by the speed of an automobile. Suppose a record of the following variables were available in respect to each mile of a long trip through many towns:

1. Time per mile.
2. Vehicles per unit area of roadway.
3. Roughness of road on a scale from (1) very smooth, to (10) very rough.
4. Traffic policemen per mile.
5. Size of city or town.
6. Cross streets per mile.
7. Width of road.

The correlation coefficients between each of the other variables and the time per mile would be high. None, to be sure, would rise to 1.0 because no one of the conditions varies in absolute harmony with the rate of speed; but all would be more than four times the probable error, for each of the other conditions has a close connection with speed. If the towns are large, the number of minutes per mile is large; if there are many rough places, many cross streets, many traffic policemen, or many vehicles, the same is true. Even the width of the road would probably give a high positive correlation, for city streets, where the time per mile is great, are generally wider than country roads where one can go fast because there is little traffic.

Such a series of "gross" correlations would afford only a partial picture. The coefficients thus obtained are of the zero order because none of the other variables is kept constant when the time per mile is compared with any given variable. Suppose now that we compare the time per mile with each of the other seven variables, and keep the remaining five variables constant. We thus, for example, simulate an experiment where the size of the towns varies, while the roads remain of constant quality, the cross streets are everywhere equally spaced, the number of policemen per mile is constant, there are exactly the same number of vehicles per unit area of road, and the roads are all of the same width. In this case the fifth order correlation coefficient between time per mile and size of towns (the five other factors being held constant) would be very small, and probably negligible. The same would be true of the fifth order correlation coefficients of time per mile with number of cross streets and with width of road. On the other hand, the fifth order correlations with vehicles per unit area and with roughness, the other factors being held constant, would be distinctly larger than the zero order coefficients. All this means merely that the size of a city, the number of cross streets, and the width of the road make no direct difference in one's speed. They are important merely because they are associated with certain other conditions such as many policemen and many vehicles per unit area. It is these other conditions which really determine one's speed, as can easily be proved by experiment. On the other hand, the roughness of the road, as well as the number of vehicles and of policemen, has a direct effect upon speed. With policemen, however, the final correlation will show a change from a positive to a negative coefficient. In spite of our almost instinctive tendency toward the opposite belief, many policemen and a small number of minutes per mile are really associated, as the method of partial correlation would show. The reason is simply that although one goes slowly where there are many traffic policemen, the policemen do not check one's speed. The thing that cuts the speed down and causes the policemen to be there is the number of vehicles on the road and the number of cross streets. The presence of the policemen actually causes the traffic to go faster than it would if it were left to itself and allowed to get tangled. In such a case the partial correlation coefficients act like an experiment and demonstrate that the presence of the policemen is in the long run a real help in increasing the speed at which one can travel with safety.

PEARL'S CORRELATION OF INFLUENZA AND ENVIRONMENT

The method of partial correlation has been effectively used in studies of environment and influenza by Pearl, Winslow, and Grove. For 34 cities in the United States Pearl used the factors indicated in Table I.

TABLE I.

1. Explosiveness of the outbreak of the epidemic, an index number based on the rapidity with which the epidemic reached its main intensity.
2. Destructiveness of the epidemic, based on the amount by which the death rate during the 25 weeks after the outbreak of the epidemic exceeded the normal death rate in the same period during 1915, 1916, and 1917.
3. Age distribution of population.
4. Sex ratio of population.
5. Density of population, or persons per acre within city limits.
6. Latitude.[*]
7. Longitude.[*]
8. Rate of growth of population, 1900-1910.
9. Normal death rate (1915, 1916, 1917) from—
   a. All causes.
   b. Pulmonary tuberculosis.
   c. Organic diseases of the heart.
   d. Acute nephritis and Bright's disease.
   e. Typhoid fever.
   f. Cancer and other malignant growths.

Taking first the group of environmental conditions, Nos. 3 to 8, Pearl compared them with the explosiveness and destructiveness of the epidemic, respectively, keeping all the other environmental factors constant. In Table II the variable which is correlated with either the explosiveness or the total destructiveness of the epidemic is indicated on the left. All the other environmental factors among Nos. 3 to 8 in Table I are held constant.

TABLE II.

Net correlation of (1) the explosiveness and (2) the destructiveness of the influenza epidemic of 1918 with demographic and environmental factors

Variable correlated with (1) and (2)	Variables held constant	Correlation coefficients of fifth order			
		(1) Explosiveness		(2) Destructiveness	
3 Age distribution of population	Nos. 4–8	+0.281	2.6[†]	+0.132	1.2[†]
4 Sex ratio of population	Nos. 3, 5–8	−0.001	0.0	+0.161	1.4
5 Density of population	Nos. 3–4, 6–8	+0.099	0.9	+0.163	1.4
6 Latitude of city	Nos. 3–5, 7–8	−0.369	3.7	−0.424	4.5
7 Longitude of city	Nos. 3–6, 8	−0.085	0.7	−0.133	1.2
8 Rate of growth of population, 1900–1910	Nos. 3–7	−0.288	2.7	−0.083	0.7

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[*] These two replace distance from Boston where the epidemic began, which was used in an earlier study.

[†] The figures in this column represent the ratio between the correlation coefficient and the probable error. For example, 4.0 means that the coefficient is four times the probable error and hence would generally be regarded as significant. If the coefficient is three times the probable error a relationship is suggested.

This table is significant because none of the coefficients, except the two where the epidemic is compared with latitude, are anywhere near four times as large as the probable error. As Pearl puts it:

> "It can, then, be safely asserted that in the determination of the variation among these 34 large American cities in respect to the excess mortality due to the epidemic, the age and sex distribution of the population, its degree of crowding, its rate of recent growth, or the distance of the city west from the Atlantic seaboard, played no appreciable part whatever. This conclusion is true whether all these factors were allowed to vary together, or whether, as in a laboratory experiment, one to five of them were held constant, while the net influence of one or more varying alone was tested.
>
> "Whether or not the same conclusion will hold generally for other cities of a different order of size, or for rural districts, remains to be shown by further work. But as to the facts for the 34 cities there can be no doubt or argument."

The environmental conditions here studied carry with them many implications as to social and industrial conditions; factory cities, for example, have a larger proportion of young people and of men than have residence cities or political centers. Hence if industrial cities suffered more or less than other types, the correlations of age and sex with the epidemic ought to be significant. Another implication of Table II seems to be that latitude, presumably through some climatic influence, had something to do with the severity of the epidemic. Winslow and Grove,* however, have shown that so far as the explosiveness of the epidemic is concerned this is not the case. When the mortality from all causes is held constant, "the correlation of explosiveness with latitude disappears entirely, being apparently of no significance." Thus we are confronted by the clear indication that none of the environmental factors thus far considered, and presumably none of the related social, industrial, and economic conditions, played any noticeable part in determining the virulence of the epidemic.

PEARL'S CORRELATION OF INFLUENZA AND DEATH RATES

Leaving, then, the search in these environmental directions, we may follow Pearl in an investigation of the relation of the influenza epidemic in large American cities to the physiological condition of the inhabitants. This investigation employed the death rates listed under No. 9 in Table I. Its results appear in Table III.

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*C.-E. A. Winslow and C. C. Grove: Note on Certain Correlation Factors of the 1918 Influenza Epidemic. The American Journal of Hygiene, Vol. II, No. 3, May, 1922.

TABLE III.

Net correlation of (1) the explosiveness and (2) the destructiveness of the influenza epidemic of 1918 with the normal death rates from certain specified causes.

Variable correlated with (1) and and (2)	* Variables held constant	Correlation coefficients of fifth order			
		(1) Explosiveness		(2) Destructiveness	
9a All causes	9b–9f	0.572	7.3*	0.405	4.2*
9b Pulmonary tuberculosis	9a, 9c–9f	0.389	4.0	0.279	2.6
9c Organic diseases of the heart	9a, 9b, 9d–9f	0.562	7.1	0.537	6.6
9d Acute nephritis and Bright's disease	9a–9c, 9e, 9f	0.307	2.9	−0.008	0.1
9e Typhoid fever	9a–9d, 9f	0.105	0.9	−0.138	1.2
9f Cancer and other malignant tumors	9a–9e	0.141	1.2	0.268	2.5

*See note on Table II.

Here, as in Table II, the correlation coefficients represent a comparison between the explosiveness and destructiveness of the epidemic on the one hand, and each of six different normal death rates on the other hand. In each comparison all the other death rates are held constant, so that the coefficients are of the fifth order. For our present purposes the second part of Table III dealing with the destructiveness of the epidemic is far more important than the part dealing with explosiveness, and will be the part on which the following discussion is based. In Table III the small as well as the large coefficients are significant. For example, the coefficients for typhoid fever are not appreciably larger than the probable error, while even the larger of the coefficients for cancer is only 2.5 times the probable error. Pearl makes an interesting comment in this connection:

> "Clearly, whatever factors, biological or environmental, or both, are measured by these death rates cannot have had any sensible influence in determining the suddenness with which the mortality curve rose during the influenza epidemic. It is generally held on good grounds that the typhoid death rate is an excellent index of the general sanitary status of a community. If it may be so accepted in the present connection, the result just stated bears out in precise mathematical terms what was obvious to the thoughtful and candid observer at the time of the epidemic, namely, that the severity with which a city was hit by the epidemic, bore no relation to its general sanitary status or to the efficiency of its health organization."

The death rates from Bright's disease and cancer are supposed to be largely independent of environmental circumstances, and hence to depend to an unusual degree on the skill of the medical practitioners. The absence of any appreciable correlation between the destructiveness of the epidemic and the death rates from cancer and Bright's disase suggests that differences in the virulence of the epidemic had little connection with the efficiency of the medical service of the various cities.

Pulmonary tuberculosis, on the contrary, is supposed to be preeminently dependent upon environment. Moreover, it affects the same organs as do influenza and pneumonia. Hence its low correlation in part 2 of Table III is surprising. A coefficient only 2.6 times the probable error gives no ground for the belief that the presence of pulmonary tuberculosis tended to increase the ravages of the epidemic.

In both parts of Table III the correlations between the epidemic and the normal death rates from all causes and from organic diseases of the heart are high. According to Pearl, this

> "indicates the overwhelming importance of the biological factor which these death rates measure in determining the explosiveness of the outbreak of epidemic mortality, as compared with the demographic and environmental factors previously considered. . . . In other words, the number of people dying during the epidemic in each of the 34 cities was determined to a significant, though not a high, degree by the usual mortality relations of the community, as indicated by the normal death rate from all causes. Cities which have normally a high death rate had also a relatively high mortality from the influenza epidemic, and vice versa those normally enjoying a relatively low mortality rate lost but relatively few persons in the epidemic. . . . It appears very clearly that of the twelve different factors here studied the normal death rate of the community from organic diseases of the heart had more to do with determining the proportionate part of the population which perished in the epidemic than any other factor."

A similar conclusion is reached by Winslow and Grove, who reexamined and tested some of Pearl's data. Their final conclusion is that

> "Pearl's discovery of the relation which the explosiveness of the epidemic bore to the normal death rate from all causes and from organic heart disease in the affected communities remains perhaps the most outstanding discovery which has been made in the study of this disease since the recent outbreak. Such a correlation, as he has demonstrated, cannot possibly be due to fortuitous circumstance. It indicates a real relation between the two factors studied. It is still important, however, to remember that a high statistical correlation may indicate either a direct or an indirect relationship. We cannot say (as some may perhaps be tempted to do) that the influenza out-

break was severe in a given community, *because* the death rate from organic heart disease had previously been high in that community. Such may have been the case; but it is equally possible that the high mortality from organic heart disease and the explosiveness of the influenza epidemic, manifest in the same communities, may have both been due to some common cause or causes affecting both, such as the racial composition of the population, or the prevalence of certain other pathogenic micro-organisms in the community. The fact of the relationship between the explosiveness (and also between the destructiveness) of the influenza epidemic and the previous normal death rate, from all causes and from organic diseases of the heart, is definite and most important. Its explanation is still problematical."

The note of caution sounded by Winslow and Grove is well advised. Although the investigations thus far recorded in this report seem to indicate that the destructiveness of the influenza epidemic was related to the death rates from all causes and especially from organic diseases of the heart more closely than to any other factor yet discussed, we shall shortly see that this apparent relation disappears when the weather is taken into consideration.

HUNTINGTON'S CORRELATION OF INFLUENZA AND WEATHER

For centuries there has been a widespread popular belief that epidemics are engendered by adverse conditions of the weather. There have also been many scientific attempts to discover the real nature of whatever correlation there may be between weather and disease.

TABLE IV.

Influenza and pneumonia compared with interdiurnal changes in temperature. (Figures in parentheses show number of days).

	Rise of 4° or more	Change of 3° or less	Drop of 4° or more
1. New York:			
A. Daily onset of influenza	21.2 (30)	10.3 (40)	−26.7 (23)*
B.	....	....	....
C. Daily deaths from influenza.	15.1 (21)	4.5 (31)	−28.2 (19)*
D. Daily deaths from pneumonia	33.1 (21)	−1.4 (32)	−31.7 (19)*
2. Boston:			
A. Daily reports of influenza	7.6 (58)	6.5 (75)	−19.2 (60)*
B. Daily reports of pneumonia.	11.3 (69)	−4.8 (83)	−6.3 (64)*
C. Daily deaths from influenza.	−8.7 (74)	10.6 (91)	−2.7 (69)
D. Daily deaths from pneumonia	19.2 (77)	−1.7 (92)	−14.4 (66)*

* Regular decline in figures from left to right.

Because of scanty data, however, and especially because of the slowness with which precise methods of correlation have come into use, previous studies have failed to be conclusive. In respect to the epidemic of 1918 Huntington* found that in New York and Boston not only the death rate but the incidence of new cases of both influenza and pneumonia declined decidedly when the temperature fell, and rose correspondingly when the temperature on any given day was higher than on the preceding day, as appears in Table IV.

Huntington's comment on this table is as follows:

> "In Table IV the first line means that in New York City during the period represented by A (*i. e.,* September 18-December 26, 1918) there were thirty days when the temperature averaged 4° or more above that of the preceding day. On those days and on the day immediately after there was an average daily increase of 21.2 per cent in the number of new cases of influenza. In the next column it appears that on (and immediately after) the 40 days with a change of 3° or less the deaths increased 10.3 per cent, while the 23 days with a drop of 4° or more in temperature show an average decrease of 26.7 per cent.
>
> "The rest of Table IV indicates that during the epidemic at New York the following conditions prevailed: (1) When the temperature rose, not only the onset of influenza, but also the deaths from both influenza and pneumonia increased notably. (2) When the temperature was stationary, the rate of onset rose somewhat, while the death rate changed but little. (3) When the temperature dropped, both the rate of onset and the death rate diminished greatly. This does not mean that low temperature is favorable, but merely that a *drop* gives a healthful stimulus. If the temperature stays low it becomes harmful. In Boston the effect of variability on the epidemic was the same as in New York except that the deaths from influenza depart somewhat from the rule and diminish when the temperature rose as well as when it fell.
>
> "Taken as a whole Table IV is surprising. In spite of the suddenness with which the epidemic fell upon the country without apparent regard to the weather, six sets of data out of seven show precisely the same relation to variability as do the 400,000 deaths from disease in general during the 8 years described above. [Daily deaths in New York City, 1877-1884.] The seventh set shows a slightly different relation like that of deaths from both kinds of pneumonia under normal conditions. . . . All alike, however, indicate unequivocally that a drop in temperature is favorable."

This result is based on only two cities and hence can be regarded only as suggestive, not conclusive. It has been criticised on the ground that "the use of *ratios* (percentages) rather than actual numbers to express diurnal increase or decrease in cases or deaths gives the same weight to the difference between one case and two as to that between 100 and 200." This criticism might be valid in some cases, but not in the one before us. A brief arithmetical calculation shows that the use of percentages greatly reduces the differences in weight assigned to different days, and thus prevents a few exceptional days from having undue weight. It was for this reason that percentages were employed.

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*Ellsworth Huntington: The Control of Pneumonia and Influenza by the Weather. Ecology, Vol. 1, No. 1, January, 1920.

The real criticism of Huntington's results lies in three facts: First, they are based on only two cities. Second, he probably assigned undue weight to humidity, for according to his own data the indications of New York are not supported by those of Boston. Third, although the incidence of influenza and the death rates from that cause and from pneumonia apparently went up and down from day to day with the temperature, there is no indication as to whether the apparent effect of a change of temperature lasted beyond the day after the change, or was soon neutralized by opposite effects on later days. In other words, so far as his results are concerned, a drop of temperature may lower both the case rate and the death rate today and the next day, but may be followed by an increased rate of both morbidity and death so that the net effect is detrimental.

DATA USED BY THE COMMITTEE ON THE ATMOSPHERE AND MAN

With the preceding facts before it, the Committee on the Atmosphere and Man undertook a further investigation of the epidemic of 1918 in the large cities of the United States. The basis of the investigation was the method of partial correlation as applied by Pearl and the indications of a relation between the epidemic and the weather as worked out by Huntington. The data used for correlation are described in Table V and are given in detail in Tables XII and XIII.

TABLE V.

Weather Factors.

A. Destructiveness of the epidemic during its first ten weeks. This is the death rate per thousand from influenza and pneumonia combined, as reported in the mortality returns of 36 large cities of the United States. It is essentially the same as No. 2 in Table I, except that 10 weeks are employed rather than 25, since a long period may have various types of weather which neutralize one another's effects. Moreover, our 10 weeks begin at different dates in different cities, according to the time of onset of the epidemic, instead of beginning at the same date everywhere. The difference between the death rates in 10 weeks and 25 is not so great as might be supposed, since the first 10 weeks of the epidemic witnessed by far the greatest mortality. The 10 weeks whose first day is hereafter regarded as the date of the onset of the epidemic are reckoned to begin with the week when the combined death rate from influenza and pneumonia rose above the normal weekly average for the year and thus began its rise to the maximum reached during the epidemic.

B. Mean daily temperature. This is the average of the maximum and minimum readings at official Weather Bureau stations. Except as otherwise noted all the weather data were furnished by the Chief of the Weather Bureau in the form of tables ready for immediate use. At some of the cities for which mortality data were available there are no official weather records. For four of these, however, at the suggestion of the Weather Bureau, the records at neighboring stations were employed, namely, New York data for Newark, Providence for Fall River, St. Paul for Minneapolis, and Boston for Cambridge.

C. Mean daily relative humidity. This is the average of relative humidities at 8 A. M. and 8 P. M. It is only an approximation, but is considered the best available figure by the Weather Bureau.

D. Estimated mean daily absolute humidity expressed in grains of moisture per cubic foot of space. On the recommendation of the Weather Bureau the estimates were based on the daily figures for B and C given above. This gives only an approximation. Nevertheless, for the six of our 36 cities which are tabulated by Day in his study of Relative Humidities and Vapor Pressures over the United States (Monthly Weather Review, Supplement No. 6, 1917), the ratio of the humidity as determined by this method to the true humidity, when a long period is considered, is 1.0005. It should be noted that since a given space at low temperature can contain only a fraction of the water vapor which can be contained in the same space at high temperature, there is almost always a high correlation between the absolute humidity and the temperature at any given station.

E. Observed daily absolute humidity at noon. The data for absolute humidities at noon were procured directly from the various local Weather Bureau stations by Professor Charles F. Brooks who has actively cooperated with the Committee. According to the Weather Bureau tables mentioned under D the mean ratio between the humidity as thus determined and the true humidity is 1.035.

F. Interdiurnal change of mean temperature, that is, the amount by which today's average temperature is above or below that of yesterday.

CORRELATION BETWEEN THE EPIDEMIC AND THE WEATHER

In order to cover the whole period during which the weather may have had some relation to the epidemic the factors listed above were averaged for periods of 10 days, 7 such periods being employed before the onset of the epidemic in each city and 5 or 6 periods thereafter.* The date of the onset, as defined above, ranged from September 8 in Boston to October 12 in a large group of cities. The various weather conditions for each 10-day period were correlated individually with the 10-week death rate from influenza and pneumonia. The results appear in Table VI, where the significant coefficients—that is, those which are more than four times the probable error—are underlined. Those more than six times the probable error are doubly underlined. The numbers in parentheses after the correlation coefficients indicate the ratio between the coefficient and its probable error.

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*All of this work and the following correlations were carried out at Clark University, partly by Dr. G. A. Coe, but chiefly by Mr. E. C. Donnelly. The original data are given in Table X at the end of this article.

This table is not easy to interpret but certain facts are clear. From the seventieth to the thirtieth day before the epidemic, no weather factor had any certain relation to the severity of the epidemic, the fairly high coefficient for variability of temperature 61-70 days before the onset of the epidemic being probably an accident. The probability is that such an accident, leading to a correlation coefficient 42 times the probable error, might occur once in 216 cases.* Then for thirty days before the epidemic the coefficient between temperature and the epidemic death rate ranged from 4.6 to 6.1 times the probable error in column II where only 32 cities are used, and from 4.8 to 6.8 times the probable error in column III where 36 cities are used. In cities where the temperature during the thirty days immediately before the epidemic was high, deaths from the epidemic were numerous; while in cool cities the death rate was relatively low. If the absolute humidity was high, the conditions were still worse, for in column VII the highest coefficient rises to more than ten times the probable error. In other words, damp heat had a worse effect than dry heat, as might be expected.

In the ten days immediately before the epidemic the effect of both temperature (column III) and absolute humidity (column VII) is decidedly less than during the two preceding periods of ten days. This may indicate that the effect lags behind its cause, or that another factor, relative humidity, assumes importance. Although the relative humidity seems to be of slight importance at most times, its coefficient (column VI) rises to 5.5 times the probable error during the 10 days immediately before the epidemic. This possibly indicates that high relative humidity fosters the growth or dissemination of the influenza bacteria. One of the most puzzling phases of the whole problem is to separate not only the physiological from the environmental influences, but the effect of the environment upon the human subject from the effect upon the disease-bringing bacteria.

As soon as the epidemic had established itself a remarkable change occurred in its relation to the weather. During the 10 days immediately after the onset of the epidemic the only phase of the weather that shows any apparent relation to the destructiveness of the epidemic is the variability of temperature (column IV). If the temperature changed greatly from day to day, or more specifically, if a cold wave happened to strike a city just when the epidemic was get-

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*R. Pearl and J. R. Miner: A Table for Estimating the Probable Significance of Statistical Constants. Me. Agr. Expt. Stat. Ann. Rept. 1914, pp. 85-88.

TABLE VI.

Correlation coefficients between (A) death rate from influenza and pneumonia during first ten weeks after onset of epidemic in 1918 and (B) Various weather conditions.

I	II	III	IV	V	VI	VII	VIII
Days before onset of epidemic	Temperature 32 cities	Temperature 36 cities	Interdiurnal change of temperature 36 cities	Interdiurnal change of temperature 32 cities	Relative humidity 36 cities	Absolute humidity estimated per Weather Bureau method 32 cities	Absolute humidity at noon
70–61	+0.120 (1.0)*	....	−0.397 (4.2)*	....	+0.161 (1.5)*	+0.218 (2.0)*	−0.004 (0.0)*
60–51	+0.102 (0.9)	....	−0.182 (1.7)	....	+0.343 (3.5)	+0.340 (3.6)	+0.272 (2.6)
50–41	+0.186 (1.6)	....	+0.301 (2.9)	....	+0.293 (2.9)	+0.341 (3.6)	+0.451 (5.1)
40–31	+0.213 (2.2)	....	+0.162 (1.5)	....	+0.116 (1.1)	+0.176 (1.6)	+0.148 (1.4)
30–21	+0.524 (6.1)	+0.531 (6.6)*	−0.071 (0.6)	−0.018 (0.2)*	+0.205 (1.9)	+0.586 (8.0)	+0.443 (4.9)
20–11	+0.510 (5.8)	+0.539 (6.8)	−0.125 (1.1)	−0.158 (1.4)	−0.050 (0.4)	+0.656 (10.4)	+0.429 (4.7)
10– 1	+0.437 (4.6)	+0.433 (4.8)	−0.071 (0.6)	−0.058 (0.5)	+0.473 (5.5)	+0.547 (7.0)	+0.542 (7.0)
Days after							
0–9	+0.166 (1.4)	....	−0.461 (5.3)	....	+0.118 (1.1)	+0.158 (1.5)	+0.177 (1.6)
10–19	+0.164 (1.4)	....	+0.348 (3.6)	....	+0.187 (1.7)	+0.204 (1.9)	+0.297 (2.9)
20–29	+0.284 (2.6)	....	−0.053 (0.5)	....	−0.088 (0.8)	+0.279 (2.7)	+0.226 (2.1)
30–39	+0.606 (8.1)	....	−0.064 (0.6)	....	−0.016 (0.1)	+0.545 (6.9)	+0.541 (6.8)
40–49	+0.359 (3.4)	....	+0.069 (0.5)	....	−0.077 (0.7)	+0.385 (4.0)	+0.313 (3.1)
50–59	+0.372 (3.6)	....	....	....	....	....	....

* See note on Table II.

ting under way, the severity of the epidemic was less than where the temperature was relatively constant. This agrees with Huntington's findings in New York and Boston, but the limitation of the relationship to a single period of ten days leaves the matter in doubt. So, too, does the fact that the correlation between the epidemic and the interdiurnal change of temperature from the 10th to the 19th days after the onset is positive, whereas the correlation for the preceding 10 days is negative.

A little later, at the height of the epidemic, or rather from the 9th to the 30th days after the onset, when the ravages of the disease were increasing most rapidly, every element of the weather ceased to have any appreciable relationship to the death rate, so far as we can yet determine. The coefficients for mean temperature, variability of temperature, absolute humidity, and relative humidity all drop to insignificant levels not appreciably larger than the probable error. In other words, the weather from the 10th to the 30th days of the epidemic apparently had nothing to do with the death rate. This is most perplexing in view of the previous high correlations. It suggests that although the bacteria could not overcome the stored-up effect of the weather of the preceding thirty days upon the human population of the cities, they were so virulent that they overcame the effect of the weather during the time when they were most active. Or possibly the kind of weather which gave vigor to man also strengthened the bacteria so that the two effects neutralized one another. The whole question is so difficult that no solution can yet be advanced even tentatively.

Between the 30th and 40th days of the epidemic there was a marked change in two respects. First, the epidemic in most places reached its maximum and began to decline. Second, the weather once more shows a marked relation to the death rate. High temperatures and high absolute humidities are correlated with a high death rate just as before, while low temperatures and low absolute humidities tend to be associated with lower mortality. It should be noted, however, that the relative rôles of temperature and absolute humidity have changed, for the coefficient between temperature and the death rate in column II (0.606) for days 30-39 after the onset of the epidemic is higher than for absolute humidity in column VII (0.545), whereas from the 20th to the 11th days previous to the onset the reverse was the case, 0.510 for temperature and 0.656 for absolute humidity. It is possible that as the weather grew colder and the amount of moisture was correspondingly lowered, the most favorable degree of absolute humidity was passed during the time of the epidemic. This would cause a change in the apparent effect of humidity. An analysis of the various weather elements for each 10-day period by means of partial correlation coefficients would probably settle this question and should ultimately be attempted.

So far as we have yet gone, the results may be summed up as follows: warm moist weather immediately before the onset of the epidemic is strongly correlated with a high death rate. A high relative humidity just before the onset is similarly, but less strongly, correlated, and may have exerted an influence by making it easy for the bacteria to be transmitted from person to person. Variable temperature and especially a cold wave immediately after the onset are correlated with a low death rate, while the weather at the climax of the epidemic shows essentially the same correlation as before the onset. The size of the correlation coefficients, from 5.3 to 10.4 times the probable error, leaves little room for doubt that the weather was somehow connected with the virulence of the epidemic. It does not, however, give any indication as to the nature of the relationship. The peculiar break in the continuity of the high coefficients needs further study, but the fact that it occurs during precisely the period when the influenza death rate was increasing most rapidly seems to suggest that the virulence of the bacteria at that time was such as to overcome the effect of the weather, provided it be true that the weather really produced an effect by increasing or decreasing the human power of resistance to the disease. It is difficult to see how this could happen, unless the atmospheric conditions which gave vigor and power of resistance to the human organism also gave vigor to the disease-bringing bacteria, but there may be some other explanation. That there is real significance not only in the strong correlations before and after the main ascending phase of the epidemic but in the break between them seems almost certain because of the size of the correlation coefficients. A coefficient 6.1 times the probable error, as in column II of Table VI, for days 30 to 21 before the epidemic, means that there is only one chance in about 20,000 that the apparent relationship is the result of accident.* A ratio of 8.1 between a coefficient and its probable error, as in column II for days 30 to 39 after the onset of the epidemic, means only one chance in more than one and one-half billion that we are confronted by an accident. In column VII, where the highest ratios between coefficients and probable errors are 6.9 after the onset of the epidemic and 10.4 before, the odds against an accidental occurrence of an apparent relationship are about 400,000 to one in the first case, and literally billions of billions to one in the second. The odds are still greater against the possibility that by mere accident either column II or column VII should twice display periods of high correlation between the epidemic and the weather. The odds against the accidental occurrence of these conditions at two highly critical times just before the onset of the epidemic and just after the main crisis are still greater. Thus the statistical fact is clear, although the explanation is still to be sought.

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*R. Pearl and J. R. Miner: A Table for Estimating the Probable Significance of Statistical Constants. Me. Agr. Expt. Stat. Ann. Rept. 1914, pp. 85-88.

METHOD OF EXPRESSING WEATHER AND CLIMATE NUMERICALLY

The peculiar time relations between influenza and the weather render it highly improbable that correlations of a higher order would greatly reduce or alter the weather correlations. Nevertheless, climate is closely related to weather and certain diseases are closely related to climate. Hence it seems advisable to employ the method of partial correlation in order to compare (1) the destructiveness of the epidemic (10-week death rate from influenza and pneumonia) with the following factors: (2) the weather, (3) climate, and (4-6) the three death rates for which Pearl found a significant correlation with either the explosiveness or the destructiveness of the epidemic, namely, (4) all causes, (5) tuberculosis, and (6) organic diseases of the heart.

Before finding the correlations between these variables and the destructiveness of the epidemic it is desirable to reduce weather and climate respectively to single expressions indicating the presumable effect of each upon man's health and vigor. For the weather two methods are available. First, we may employ a single factor for a definite period. Absolute humidity as given in column VII of Table VI represents the combined effect of temperature and humidity. It also shows the highest correlation with the death rate during the main phase of the epidemic. Hence the absolute humidity for thirty days before the onset of the epidemic is the best single expression of the weather for our purpose. Data for individual cities appear in Table XIII. The objection to this method is that it takes no account of the other significant correlations in Table VI. Such neglect of conditions which are closely correlated with the severity of the epidemic would seem highly illogical. Hence we have employed a second method and have combined the effect of all the weather factors whose zero order correlations with the epidemic amount to at least 4.5 times their probable errors. The data employed for this purpose are given in Table VII. In using this table the departures of the four weather conditions at each city from the averages for the 36 cities were weighted so that the sums of their respective squares were in approximately the same ratio as the squares of the correlation coefficients in Table VII. The four weighted departures for each city were then added, thus giving a single expression (Table XII). In this the mean temperature plays much the larger rôle, since it figures in both A and B of Table VII; relative humidity and variability of temperature play minor and nearly equal rôles, while the effect of absolute humidity cannot be separated from that of temperature. As a matter of fact it makes practically no difference whether we use both A and B of Table VII or only one of them in obtaining the single expression for weather. Using B, C, and D, the correlation coefficient between the weather and the death rate for the first 10 weeks of the epidemic is + 0.665 ± 0.062 (10.7 times the probable error); while when A, B, C, and D, are employed, the coefficient is + 0.667.*

TABLE VII.

Weather condition	Correlation coefficient with 10-week death rate during epidemic	Square of correlation coefficient
A. Mean daily temperature 11–30 days before and 30–39 days after onset of epidemic...	+0.580	0.334
B. Estimated mean daily absolute humidity for same periods....................	+0.620	0.384
C. Relative humidity 1–10 days before onset of epidemic..........................	+0.473	0.224
D. Interdiurnal change of temperature 0–9 days after onset of epidemic...........	−0.461	0.213

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*After this report was in final form the suggestions of friendly critics led to an investigation of the first of the methods outlined above, that is, the correlation of the destructiveness of the epidemic with the most important single section of the weather instead of with all the weather conditions which appear to be important. In the zero order coefficients this more limited method gives results which at first sight seem almost identical with those of the method described in the text, as appears in Table VIII. In the fourth order correlations, however, as described below, this method gives a coefficient of only +0.258 (2.4 times the probable error) when the weather (absolute humidity for 30 days) is compared with the destructiveness of the epidemic, and climatic energy and the death rates from all causes, organic diseases of the heart, and pulmonary tuberculosis are held constant. The corresponding fourth order correlation when all conditions of the weather are taken into account is +0.570. This last coefficient is 7.6 times the probable error, so that there is only one chance in several million that it can be the result of an accident. The contrast between this coefficient and the other illustrates the great delicacy and precision of the method of partial correlations in true relations from those that are false.

TABLE VIII.

Zero order correlation coefficients between weather of epidemic, expressed by two methods, and death rates, and climate.

Variable	Method I Correlation coefficient with weather index	Method II Correlation coefficient with estimated absolute humidity 30 days before onset of epidemic	Difference Excess of II over I
Death rate from pulmonary tuberculosis	+0.489	+0.516	+0.027
Death rate from organic diseases of the heart	+0.436	+0.489	+0.053
Death rate from all causes	+0.464	+0.463	−0.001
Death rate from epidemic (first 10 weeks)	+0.667	+0.582	−0.085
Climatic energy	−0.442	−0.583	+0.141

Climate is very different from weather. The weather before and during the epidemic in Boston, for example, was decidedly unfavorable while the weather at Cleveland was highly favorable. Yet there is little real choice between the climates of the two cities. No final data as to the effect of climate on human activity are yet available, although the Committee on the Atmosphere and Man, in cooperation with insurance companies, factories, and the Taylor Instrument Companies, has undertaken investigations which in a few years ought to furnish such data. For the present the best that can be done is to use Huntington's map of "climatic energy." As originally published in *Civilization and Climate,* the map was based on the daily achievements of piece workers in factories and of students at West Point and Annapolis. Later it was slightly modified by monthly data for about 10 million deaths which were compared with the weather in the cities of the United States, France, and Italy. It must be clearly understood that the distribution of death rates from city to city played no part in the construction of this map. The sole basis is variations in efficiency and to a slight extent in the death rate *in individual cities from one month to another.* Thus a high death rate in a southern city in summer often has only a small effect on the construction of the map because the rate departed only a little from the normal for the whole year. Its effect in many cases is much less than that of a high winter death rate in a northern city where the normal death rate for the year is low, but where the winter departure from the city's yearly normal was great. The monthly variations in the death rate, however, play only a small part in the map because they agree closely with the map as previously drawn on the basis of the work of factory operatives and students. The latest form of the map of climatic energy appears in *Business Geography,* by Huntington and Williams. From it the climatic energy of each city has been estimated, thus giving a figure which shows the probable degree of resistance to disease that would be expected on the basis of climate alone. The figures thus obtained are merely a first approximation and must be interpreted as open to revision. They are given in Table XII under the heading "climatic energy."

TABLE IX.

Correlation coefficients between death rates, climate, and weather.

Six factors are here involved, namely:

A. Normal death rate (1915, 1916, 1917) from all causes.
B. Normal death rate (1915, 1916, 1917) from pulmonary tuberculosis.
C. Normal death rate (1915, 1916, 1917) from organic diseases of the heart.
D. 10-week death rate from epidemic.
E. Climatic energy.
F. Weather before and during epidemic.

Part I. Epidemic not included among variable factors.

Variable factors	Zero order coefficient	Factors held constant	Fourth order coefficient
1. Death rates from tuberculosis (B) and all causes (A).......	+0.731 (14.0)	C D E F	+0.542 (6.9)
2. Death rates from tuberculosis (B) and heart diseases (C)...	+0.682 (11.4)	A D E F	+0.439 (4.9)
3. Death rate from tuberculosis (B) and climatic energy (E)..	−0.508 (6.1)	A C D F	−0.431 (4.7)
4. Death rate from tuberculosis (B) and weather during the epidemic (F)..................	+0.489 (5.8)	A C D E	+0.053 (0.5)
5. Death rates from all causes (A) and heart diseases (C).......	+0.609 (8.6)	B D E F	−0.088 (0.8)
6. Death rate from all causes (A) and climatic energy (E).....	−0.394 (4.2)	B C D F	−0.113 (1.0)
7. Death rate from all causes (A) and weather during the epidemic (F)..................	+0.464 (5.2)	B C D E	−0.037 (0.3)
8. Death rate from heart diseases (C) and climatic energy (E)..	−0.202 (1.9)	A B D F	+0.198 (1.8)
9. Death rate from heart diseases (C) and weather during the epidemic (F)...............	+0.436 (4.8)	A B D E	−0.044 (0.4)
10. Climatic energy (E) and weather during the epidemic (F)..	−0.442 (4.9)	A B C D	−0.372 (3.9)

CORRELATIONS OF DESTRUCTIVENESS OF INFLUENZA EPIDEMIC WITH NORMAL DEATH RATES, WEATHER, AND CLIMATE

The correlation coefficients between the 10-week death rate from influenza and pneumonia on the one hand, and weather, climate, and the normal death rates from all causes, tuberculosis, and heart diseases on the other, are given in Table IX. The first column of figures shows the gross correlation coefficients, that is, those of the zero order, between each pair of variables, all of the other variables named at the head of the table being allowed to vary at will. Among the 15 zero order coefficients all but two are more than four times their probable errors, and 7 are more than 6 times their probable errors. Such large coefficients suggest a high degree of interrelationship. The second set of coefficients shows what happens when the epidemic death rate is compared with any one of the other variables and the remaining four are kept constant. Here only four correlations are of significant size.

Part II. Epidemic included among variable factors.

Variable factors	Zero order coefficient	Factors held constant	Fourth order coefficient
11. Death rates from the epidemic (D) and from all causes (A)..	+0.569 (7.5)	B C E F	+0.271 (2.6)
12. Death rates from the epidemic (D) and from tuberculosis (B)	+0.491 (5.8)	A C E F	−0.099 (0.9)
13. Death rates from the epidemic (D) and from heart diseases (C)	+0.592 (8.1)	A B E F	+0.306 (3.0)
14. Death rate from the epidemic (D) and climatic energy (E)...	−0.200 (1.9)	A B C F	+0.202 (1.9)
15. Death rate from the epidemic (D) and weather during the epidemic (F)...............	+0.667 (10.7)	A B C E	+0.570 (7.6)

TABLE X.

Diminution in apparent relation between epidemic destructiveness and normal death rates when climate and weather are taken into account.

Variable death rates	Data from Table III		Data from Table IX	
	Factors held constant	Fifth order coefficients	Factors held constant	Fourth order coefficients
Epidemic and heart diseases (9c or C)..	9a 9b 9d 9e 9f	+0.537 (6.6)	A B E F	+0.306 (3.0)
Epidemic and all causes (9a or A)...	9b 9c 9d 9e 9f	+0.405 (4.2)	B C E F	+0.271 (2.6)
Epidemic and tuberculosis (9b or B)..	9a 9c 9d 9e 9f	+0.279 (2.6)	A C E F	−0.099 (0.9)

This table suggests many interesting lines of investigation, but we shall discuss only those which pertain directly to the epidemic, and are included in Part II. One of the main features of Table IX is that in the fourth order correlations in Part II the apparent relation between the destructiveness of the epidemic and the normal death rates from other causes is much less than in Table III, as may be seen in Table X.

In the first part of Table X the factors aside from the destructiveness of the epidemic are the normal death rates from the following causes, *9a* all causes, *9b* pulmonary tuberculosis, *9c* organic heart diseases, *9d* acute nephritis and Bright's disease, *9e* typhoid fever, and *9f* cancer. In the second part of the table the corresponding factors are A = *9a*, B = *9b*, C = *9c*, E = climatic energy, and F = weather. The low fourth order correlations in the second part of the table are due to the fact that weather and climate are there held constant, whereas they are allowed to vary in the fifth order correlations of the other part of the table. The fact that in the second part of Table X no coefficient is more than three times the probable error suggests that there is no appreciable causal relationship between the destructiveness of the epidemic during the ten weeks of the main onslaught and the normal mortality from any disease yet investigated. There is indeed a fairly close agreement between the normal death rates from several diseases, especially organic diseases of the heart, and the destructiveness of the epidemic, as measured by the zero order coefficients, but this is only because these diseases and the epidemic are both related to certain other conditions among which those pertaining to climate are the only ones that have been detected up to this point.

The other outstanding fact in Part II of Table IX is that when the climate and the deaths from all causes, from organic diseases of the heart, and from pulmonary tuberculosis are held constant, the correlation between the destructiveness of the epidemic and the weather still remains strong. No other variable thus far studied appears to have any appreciable causal relation to the destructiveness of the epidemic, for in every other case the coefficients sink to a level not over three times the probable error. This means that even in the case of deaths from organic diseases of the heart there is one chance in 22 that the apparent connection shown in Part II of Table IX may be accidental. In the same way the correlation between the weather and the destructiveness of the epidemic is reduced to insignificant proportions if only part of the effective weather conditions are employed. On the contrary, when all the significant weather conditions are combined and the resulting index is compared with the destructiveness of the epidemic, the resultant correlation coefficient remains large no matter what other conditions are held constant. There is only one chance in several million that the apparent connection between the weather and the epidemic is accidental.

At this point there arises the question whether the introduction of some other factor might not reduce or even extinguish the apparent relationship between the weather and the influenza epidemic just as the introduction of the weather reduces the apparent relationship between the influenza on the one hand, and deaths from organic heart diseases and from all causes on the other hand, and extinguishes the apparent relation between influenza and tuberculosis. The two most obvious factors that suggest themselves in this connection are the racial composition of the population and the degree to which people are engaged in manufacturing.

The best available method of testing these factors seems to be to use the percentages of foreign born, of negroes and of wage earners as given for our 36 cities in the census of 1920. These percentages give the following correlations of the zero order when compared with the death rate from the epidemic:

A. Percentage of foreign born............	+ 0.077
B. Percentage of negroes................	+ 0.190
C. Percentage of wage earners............	+ 0.049

TABLE XI.

Correlation coefficients between weather and 10-week death rate from influenza in 1918 when various factors are held constant.

Factors held constant	Correlation coefficient	Ratio of coefficient to probable error
None..	+0.667	10.8
Normal death rate from all causes................	+0.552	7.2
Normal death rate from tuberculosis...............	+0.560	7.3
Normal death rate from organic diseases of the heart...	+0.563	7.4
Climatic energy................................	+0.664	10.6
Percentage of foreign born whites, 1920............	+0.671	10.9
Percentage of negroes, 1920......................	+0.670	10.8
Percentage of wage earners, 1920..................	+0.671	10.9
Climatic energy, and death rates from all causes, from tuberculosis, and from heart diseases.............	+0.570	7.6
Percentages of foreign born, negroes, and wage earners.	+0.620	9.0

As the largest of these is only 1.8 times the probable error, they are of no significance. This conclusion is confirmed by the correlation coefficients of higher orders when the epidemic and the weather are allowed to vary while certain other variables are kept constant, as indicated in Table XI. A study of these coefficients and especially of the last two makes it evident that so far as racial composition and industrial condition are measured by the percentages of foreign born, of negroes, and of wage earners, these conditions were even less important than the normal death rates as real determinants of the severity of the influenza epidemic in the autumn of 1918 in our 36 large cities. Thus the statistical fact is clear. The weather, which means primarily the weather just before the onset of the epidemic and at or just after the climax, is the one factor thus far investigated which shows a clear, pronounced, and persistent relation to the destructiveness of the epidemic.

SUMMARY AND CONCLUSION

The significant fact of the investigation here set forth lies in this: By means of partial correlations we have examined the relation of the destructiveness of the influenza epidemic of 1918 to a great number of conditions in the large cities of the United States so far as the necessary data are available. The conditions investigated appear to include all the environmental and human factors that have thus far been suggested as causes of variations in the destructiveness of the epidemic. They do not include certain possible factors pertaining to the disease-bringing bacteria, for as to these no exact data are available. The factors thus far available may be classified as follows:

A. Demography:
  1. Age distribution of the population.
  2. Ratio of the sexes.
  3. Density of the population.
  4. Rate of growth from 1900 to 1910.

B. Position:
  5. Distance from Boston.
  6. Longitude.
  7. Latitude.

C. Normal death rates, 1915, 1916, 1917:
  8. All causes.
  9. Pulmonary tuberculosis.
  10. Organic diseases of the heart.
  11. Nephritis and acute Bright's disease.
  12. Typhoid fever. (Sanitary index.)
  13. Cancer and other malignant tumors.

D. Racial factors:
  14. Percentage of negroes, 1920.
  15. Percentage of foreign born, 1920.

E. Industry:
  16. Percentage of wage earners, 1920.

F. Climate and weather:
  17. Mean temperature.
  18. Change of mean temperature from one day to the next.
  19. Absolute humidity.
  20. Relative humidity.
  21. Weather.
  22. Climatic energy.

Directly or indirectly these twenty-two factors embrace almost every non-bacterial condition which may have been effective in causing the virulence of the epidemic to vary from city to city. Among the twenty-two factors the only ones that have zero order correlation coefficients more than four times the probable error, when compared with the destructiveness of the influenza epidemic, are the normal death rates from all causes, from pulmonary tuberculosis, and from organic diseases of the heart; four factors which pertain to the weather, namely, mean temperature, change of mean temperature, absolute humidity, and relative humidity; and a combination of the last four which may stand as representative of the weather in general. The death rates from various causes, however, all sink to insignificance when the weather, or the most representative single factor of the weather, namely, the absolute humidity, is held constant. Thus among all the factors yet investigated only the weather appears to have had any fundamental significance in causing the destructiveness of the epidemic to vary from city to city. This does not mean that the weather was in any sense a cause of the epidemic. It is even possible that the weather may be related to the epidemic only indirectly, as is the case with the death rate from heart disease, although no factor capable of producing this result has yet been suggested. Even if the weather is a causal factor in producing variations in the virulence of the epidemic, there is no reason to think that it is the only factor. If the degree of relationship between two variables is proportional to the square of the correlation coefficient, as is sometimes held, the weather, even if it is a direct agent, may be responsible for no more than a third of the variations from city to city. Nor do our high correlation coefficients mean that the weather had anything to do with setting the date of the epidemic or with determining the severity of the 1918 epidemic compared with other epidemics. Neither do they prove anything as to the effect of the weather in other countries, although elsewhere a relationship similar to that found in the United States seems probable. For instance, the British government estimates that in India the death rate from the epidemic was about six times as great as in the United States, while scanty reports from other tropical countries indicate a similar excessive mortality. The one thing which seems clear from the present investigation is that the weather is the one factor whose apparent relationship to the epidemic is not seriously reduced or modified when other conditions are held constant.

The results of this investigation should be qualified in still another respect. It is not necessary to suppose that other epidemics will show exactly the same relationships as the epidemic of 1918, even though they may be strongly influenced by the weather. In the first place, the epidemic of 1918 was so peculiar in its virulence, its rapid dissemination, its fatality for persons in the prime of life, and in other respects, that it may well have been peculiar in its climatic relationships. In the second place, the epidemic occurred at a season when the approach of cold weather normally exerts a strong stimulating effect in the United States. It is well known that from August to October or even November the death rate normally declines. The epidemic seems to have reflected this condition. Just so far as the weather approached the conditions which prevail at the time when the autumn mortality is lowest, the ravages of the epidemic were checked. At some other, colder season, relatively low temperature and low humidity might be as harmful as high temperature and high humidity appear to have been in September, October, and November, 1918. As a matter of fact, the epidemic of February and March, 1919, shows only a small positive correlation between the monthly death rate and the temperature. Other conditions, perhaps other conditions of weather, were then dominant; or possibly some cities were too cold while others were too warm, a condition which would make the use of correlation coefficients impracticable.

Finally, even if the weather should prove to be an important factor in causing variations in the virulence of influenza, we still have little evidence as to how its effects are produced. Presumably the weather gives to the human being more or less power of resistance to disease. But it is not improbable that the weather also has an important effect upon the vigor, reproductive rate, or transmission of the disease-bringing bacteria. One of the main purposes of this report is not only to call attention to the urgent necessity of investigating and of applying to other regions and other epidemics the methods here employed, but to urge the necessity of further experiments to determine just how the human subject and the bacteria are influenced by the atmosphere and by other conditions which may increase or diminish the ravages of influenza.

TABLE XII

Destructiveness of influenza epidemic, 1918, and factors which may have influenced the destructiveness.

Cities	10-weeks death rate per thousand from influenza and pneumonia	Normal death rates per hundred thousand, 1915–1916–1917			Combined weather index	Climatic energy	Mortality rates of general regions of the various cities per experience of three insurance companies. 100 = normal expectation
		All causes	Organic diseases of heart	Tuberculosis			
Albany......	5.3	1947.0	236.4	224.5	− 4.4	124	94
Baltimore...	6.4	1810.3	195.9	202.7	27.3	114	98
Birmingham.	3.1	1662.5	107.6	175.0	37.1	95	118
Boston......	5.7	1651.6	211.5	143.8	17.3	124	92
Buffalo......	4.8	1566.4	165.9	146.0	8.1	124	94
Cambridge...	4.5	1354.4	183.9	178.8	24.0	124	92
Chicago.....	3.5	1457.1	159.1	139.5	− 2.5	124	88
Cleveland...	3.3	1462.1	118.8	132.8	−25.8	123	90
Columbus...	2.3	1498.3	155.7	131.8	−24.6	116	93
Dayton.....	4.1	1492.7	184.3	139.2	−28.9	115	93
Denver......	3.9	1225.9	108.8	218.9	−31.3	120	97
Fall River...	5.5	1639.4	164.0	139.6	11.2	123	94
Grand Rapids	1.1	1258.8	146.4	76.3	−40.3	124	91
Indianapolis.	2.4	1550.2	185.7	164.2	10.3	118	91
Kansas City.	3.5	1518.9	143.7	149.7	−23.9	121	90
Los Angeles..	3.3	1238.2	156.0	182.1	31.7	118	96
Louisville....	3.0	1542.1	164.7	160.1	−19.9	108	103
Milwaukee...	1.8	1214.4	100.7	82.4	−10.8	124	89
Minneapolis..	1.8	1189.4	114.1	120.4	−20.9	123	88
Nashville....	5.2	1683.7	198.7	188.3	5.2	102	115
Newark.....	4.4	1412.2	148.3	151.0	18.0	121	98
New Haven..	5.1	1660.0	185.4	103.6	28.0	122	94
New Orleans.	5.6	1893.0	224.4	270.9	62.4	80	125
New York...	4.1	1384.7	165.3	160.5	4.7	122	98
Philadelphia.	7.4	1630.1	203.5	169.9	24.9	118	94
Pittsburgh...	6.3	1694.0	134.5	115.9	14.5	118	94
Portland, Ore	2.7	804.0	92.3	58.4	− 8.6	123	88
Providence..	4.1	1527.0	152.8	133.3	11.2	123	94
Richmond...	4.2	1903.1	196.8	174.9	14.1	108	113
St. Louis....	2.2	1458.0	141.3	132.2	−26.5	116	94
St. Paul.....	2.7	1093.0	118.9	106.6	−44.7	123	88
San Francisco	4.7	1546.5	237.2	170.0	7.9	120	94
Seattle......	2.4	711.9	83.9	53.7	− 5.5	125	90
Spokane.....	3.1	750.3	68.7	46.6	−29.9	110	96
Toledo......	2.0	1705.1	185.2	173.7	−35.0	122	90
Washington..	5.2	1796.6	235.1	185.5	35.2	113	98

TABLE XIII

The weather of the influenza epidemic of 1918

Part 1

Cities	70–61 days before onset of epidemic				
	Mean temperature	Interdiurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany	80.0	37	67.0	.69	.68
Baltimore	77.8	32	63.7	.62	.52
Birmingham	78.8	24	77.1	.76	.67
Boston	64.3	36	81.6	.50	.46
Buffalo	72.2	40	68.7	.52	.52
Cambridge	74.7	39	76.3	.67	.69
Chicago	74.0	42	64.3	.55	.53
Cleveland	76.8	33	70.5	.45	.63
Columbus	76.9	33	75.4	.71	.68
Dayton	77.1	45	67.0	.63	.58
Denver	71.5	35	57.1	.42	.35
Fall River	68.2	37	73.3	.50	.48
Grand Rapids	72.3	49	59.2	.48	.46
Indianapolis	75.9	34	58.1	.53	.47
Kansas City	82.7	40	49.0	.56	.47
Los Angeles	68.9	16	84.4	.61	.50
Louisville	79.0	32	72.3	.72	.70
Milwaukee	71.7	34	74.0	.59	.60
Minneapolis	74.8	41	73.8	.48	.68
Nashville	79.1	21	77.2	.78	.67
Newark	76.8	32	62.5	.57	.50
New Haven	75.5	22	69.7	.62	.58
New Orleans	83.4	18	80.8	.93	.81
New York	69.8	33	64.5	.48	.45
Philadelphia	78.4	29	62.4	.60	.55
Pittsburgh	74.5	24	57.1	.50	.39
Portland, Ore.	69.6	34	60.1	.44	.39
Providence	68.2	37	73.3	.51	.48
Richmond	77.6	14	77.2	.75	.66
St. Louis	83.6	42	45.1	.53	.47
St. Paul	71.2	58	69.1	.53	.52
San Francisco	60.6	18	81.6	.44	.41
Seattle	64.3	20	70.8	.42	.41
Spokane	72.6	35	43.0	.36	.34
Toledo	73.6	77	66.2	.55	.53
Washington	76.8	22	68.0	.63	.50

TABLE XIII.

Cities	Part 2 60–51 days before onset					Part 3 50–41 days before onset				
	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany	74.7	50	66.6	.58	.53	70.6	46	71.1	.55	.52
Baltimore	77.9	36	74.0	.71	.62	83.0	46	71.9	.82	.75
Birmingham	77.4	15	79.8	.74	.74	82.6	26	73.8	.82	.70
Boston	70.4	42	81.6	.61	.58	77.8	52	75.9	.73	.62
Buffalo	72.8	20	67.2	.55	.59	74.1	32	75.0	.64	.67
Cambridge	74.1	68	79.5	.68	.51	69.6	58	79.6	.58	.47
Chicago	72.7	49	74.2	.59	.59	80.6	77	63.8	.67	.58
Cleveland	76.0	57	62.4	.57	.57	74.7	42	61.4	.53	.56
Columbus	80.4	32	65.7	.69	.58	78.3	22	63.9	.62	.62
Dayton	83.7	17	63.6	.73	.64	75.6	29	66.5	.59	.58
Denver	74.2	22	52.7	.46	.36	69.8	18	61.5	.46	.35
Fall River	75.7	34	74.6	.65	.59	73.3	57	75.1	.62	.57
Grand Rapids	76.1	64	60.6	.56	.54	75.3	26	59.1	.51	.47
Indianapolis	75.5	42	67.5	.60	.51	84.6	31	61.4	.72	.62
Kansas City	86.1	47	43.2	.55	.46	85.6	31	53.8	.66	.54
Los Angeles	76.3	34	66.4	.60	.56	67.3	8	75.3	.41	.46
Louisville	82.3	40	55.7	.62	.59	84.1	40	64.5	.77	.56
Milwaukee	68.5	38	75.9	.53	.56	74.2	52	71.2	.61	.57
Minneapolis	71.5	40	71.7	.56	.52	72.8	35	73.0	.60	.60
Nashville	80.4	26	65.2	.68	.61	85.1	18	62.4	.75	.62
Newark	74.3	38	79.6	.68	.61	77.4	66	75.0	.72	.63
New Haven	73.3	42	80.2	.67	.60	74.8	51	77.9	.68	.66
New Orleans	82.8	20	83.1	.94	.80	83.5	21	80.4	.93	.84
New York	77.0	36	67.5	.63	.55	73.8	41	75.9	.64	.58
Philadelphia	77.4	32	73.8	.70	.66	73.6	52	71.8	.59	.71
Pittsburgh	75.8	26	64.7	.58	.51	83.3	36	64.3	.72	.67
Portland, Ore.	64.2	15	64.5	.39	.37	66.9	24	68.6	.45	.42
Providence	75.7	34	74.6	.67	.59	73.3	57	75.1	.63	.57
Richmond	79.6	48	80.0	.82	.65	79.5	24	77.6	.78	.70
St. Louis	85.6	32	58.6	.73	.62	79.2	30	76.3	.77	.66
St. Paul	71.1	27	72.0	.55	.58	72.2	39	70.8	.56	.57
San Francisco	59.7	23	78.5	.40	.38	60.8	21	83.3	.45	.41
Seattle	60.8	21	77.4	.41	.39	61.8	27	81.6	.43	.42
Spokane	63.8	53	51.7	.32	.27	64.7	27	58.5	.36	.32
Toledo	80.2	48	65.5	.68	.63	74.9	32	71.4	.63	.58
Washington	77.3	34	78.5	.73	.64	83.4	34	75.2	.86	.76

TABLE XIII.

Cities	Part 4 40–31 days before onset					Part 5 30–21 days before onset				
	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany......	73.4	33	71.0	.59	.54	66.0	37	75.3	.49	.43
Baltimore....	74.6	31	65.4	.57	.49	77.5	36	71.6	.66	.61
Birmingham..	82.0	16	68.8	.76	.52	80.3	24	69.1	.72	.57
Boston......	71.4	68	75.9	.60	.51	70.4	54	74.6	.56	.43
Buffalo......	69.2	36	66.6	.48	.47	68.9	28	73.2	.53	.50
Cambridge...	65.1	52	63.8	.41	.49	70.8	40	77.6	.60	.49
Chicago.....	74.5	32	71.1	.60	.62	73.0	40	65.9	.53	.52
Cleveland....	73.3	20	68.5	.56	.57	65.1	25	70.1	.44	.43
Columbus....	75.0	24	72.6	.63	.64	66.2	30	75.4	.49	.55
Dayton......	69.3	26	81.1	.58	.54	62.2	33	77.6	.44	.37
Denver......	69.2	39	44.7	.33	.23	59.7	73	66.8	.34	.28
Fall River...	75.5	65	80.7	.71	.66	70.7	35	66.8	.51	.48
Grand Rapids	65.4	29	68.6	.44	.40	59.3	25	73.7	.38	.34
Indianapolis..	78.2	29	66.5	.67	.61	72.0	28	76.3	.60	.59
Kansas City.	81.0	26	59.6	.64	.55	66.2	49	73.5	.50	.44
Los Angeles..	71.8	18	76.5	.59	.55	67.0	26	74.6	.44	.52
Louisville....	77.5	26	70.8	.67	.59	70.0	28	72.4	.53	.47
Milwaukee...	72.9	47	75.9	.63	.58	70.9	41	70.7	.54	.57
Minneapolis..	70.8	33	74.5	.57	.59	68.4	40	69.2	.48	.50
Nashville....	77.7	18	67.4	.65	.52	73.8	30	73.7	.52	.49
Newark......	72.2	30	66.0	.50	.48	74.2	30	52.7	.44	.56
New Haven..	71.7	39	69.5	.54	.50	72.0	28	79.9	.63	.57
New Orleans.	80.3	23	84.4	.87	.80	80.6	21	81.1	.84	.87
New York...	79.1	63	75.3	.76	.65	72.2	22	65.3	.51	.49
Philadelphia..	74.7	27	67.8	.59	.52	76.6	31	70.6	.64	.61
Pittsburgh...	73.0	36	64.7	.53	.53	73.5	26	73.7	.60	.58
Portland, Ore.	71.7	40	49.5	.39	.32	68.4	39	67.0	.47	.45
Providence...	75.5	65	80.7	.71	.66	70.7	35	68.2	.53	.48
Richmond...	74.3	22	77.0	.56	.62	72.7	32	79.4	.64	.52
St. Louis....	69.4	28	75.7	.55	.50	68.5	31	62.0	.44	.37
St. Paul.....	61.8	48	71.7	.39	.44	57.4	63	77.1	.36	.41
San Francisco	61.7	23	85.4	.47	.45	63.2	26	85.5	.48	.49
Seattle......	67.2	25	60.2	.40	.37	62.2	30	74.9	.42	.41
Spokane.....	64.4	42	44.8	.28	.32	65.8	32	52.8	.34	.41
Toledo......	67.2	29	72.5	.48	.47	60.9	35	75.1	.40	.35
Washington..	72.9	34	72.0	.59	.50	76.6	26	79.2	.73	.62

Cities	Part 6 20–11 days before onset					Part 7 10–1 days before onset				
	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany	60.6	51	78.8	.41	.40	54.3	54	76.2	.32	.33
Baltimore	67.7	38	70.0	.48	.44	65.6	48	75.8	.49	.41
Birmingham	72.1	29	80.7	.64	.58	70.6	46	69.6	.53	.43
Boston	72.3	47	68.7	.54	.48	66.5	33	79.9	.52	.52
Buffalo	61.5	36	73.9	.44	.37	54.1	44	80.3	.34	.33
Cambridge	63.4	42	74.1	.45	.51	61.8	52	83.2	.46	.42
Chicago	63.7	38	73.6	.47	.40	55.8	40	70.3	.31	.32
Cleveland	58.8	42	77.5	.40	.36	53.5	41	70.9	.30	.26
Columbus	60.4	40	81.3	.43	.46	53.3	47	71.7	.30	.29
Dayton	53.7	40	79.8	.33	.33	59.4	57	70.1	.36	.34
Denver	58.3	80	68.9	.33	.28	58.1	58	66.3	.32	.28
Fall River	68.0	33	75.2	.52	.52	60.9	47	79.5	.43	.41
Grand Rapids	52.5	30	74.5	.30	.28	53.3	54	70.2	.29	.26
Indianapolis	65.1	28	72.2	.45	.42	55.9	46	76.5	.34	.33
Kansas City	66.1	47	60.7	.39	.37	60.3	42	55.6	.29	.25
Los Angeles	73.3	40	72.1	.60	.56	70.7	23	76.0	.56	.50
Louisville	64.7	42	71.5	.44	.38	56.6	44	68.4	.32	.29
Milwaukee	61.4	42	75.6	.50	.41	53.9	44	70.7	.29	.31
Minneapolis	57.2	68	74.0	.35	.38	50.3	47	78.6	.28	.32
Nashville	67.7	40	63.4	.45	.37	61.0	42	72.1	.39	.31
Newark	66.0	42	66.6	.42	.43	63.7	54	78.3	.46	.45
New Haven	64.3	45	75.2	.46	.43	61.4	51	82.7	.44	.46
New Orleans	80.2	15	68.5	.71	.73	71.1	47	81.7	.62	.62
New York	72.5	32	73.6	.59	.50	63.9	42	72.8	.44	.41
Philadelphia	67.9	35	70.8	.48	.43	66.3	49	75.4	.43	.47
Pittsburgh	64.9	26	75.8	.47	.44	58.0	38	76.1	.37	.25
Portland, Ore.	64.2	39	63.1	.39	.35	64.1	36	70.9	.37	.37
Providence	68.0	33	75.2	.52	.52	60.9	47	79.5	.43	.41
Richmond	67.6	31	76.6	.52	.46	61.7	44	81.5	.45	.35
St. Louis	57.8	44	70.4	.34	.29	64.4	47	59.9	.36	.32
St. Paul	51.7	47	75.6	.30	.33	54.0	53	61.8	.26	.25
San Francisco	62.0	21	81.8	.46	.42	62.4	8	79.9	.45	.43
Seattle	58.7	19	73.1	.37	.37	61.2	33	75.8	.36	.39
Spokane	63.1	26	52.8	.31	.30	63.1	32	59.0	.34	.35
Toledo	52.4	36	76.4	.30	.30	55.9	70	69.9	.31	.29
Washington	67.2	36	75.5	.50	.45	65.4	52	79.7	.50	.42

TABLE XIII.

Cities	Part 8 0–9 days after onset					Part 9 10–19 days after onset				
	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany......	52.1	36	73.0	.29	.29	53.4	60	76.3	.31	.30
Baltimore....	60.0	33	63.6	.33	.29	61.7	66	71.9	.41	.35
Birmingham..	67.7	46	74.1	.50	.43	73.0	24	59.8	.57	.51
Boston......	60.6	46	77.3	.40	.45	57.6	48	76.5	.37	.44
Buffalo......	52.0	44	74.7	.29	.25	54.6	64	73.4	.34	.33
Cambridge...	52.2	34	69.9	.28	.40	56.0	48	75.3	.34	.42
Chicago.....	57.1	42	65.7	.31	.28	61.5	50	64.8	.36	.34
Cleveland....	56.0	69	75.0	.34	.33	57.2	50	64.4	.30	.30
Columbus....	58.7	65	71.8	.35	.35	58.7	48	65.6	.32	.36
Dayton....	57.9	56	73.8	.36	.31	58.8	34	75.5	.38	.35
Denver......	60.3	43	62.7	.33	.25	59.9	42	56.1	.29	.23
Fall River...	60.3	37	79.4	.42	.41	55.5	43	68.6	.30	.28
Grand Rapids	55.9	61	70.0	.31	.28	52.9	33	71.8	.29	.28
Indianapolis..	56.9	46	61.7	.29	.25	62.9	69	67.9	.39	.37
Kansas City..	67.7	44	60.1	.41	.36	65.9	30	63.9	.41	.40
Los Angeles..	73.7	21	75.5	.64	.57	71.1	28	65.2	.50	.43
Louisville....	65.3	64	62.4	.39	.34	63.2	26	67.0	.39	.32
Milwaukee...	55.2	50	67.8	.30	.28	58.9	64	69.6	.35	.29
Minneapolis..	56.0	54	61.9	.29	.30	57.5	37	68.7	.33	.31
Nashville....	69.6	40	57.9	.41	.42	63.5	32	67.9	.39	.42
Newark.....	57.5	34	63.8	.30	.28	59.0	55	66.6	.33	.32
New Haven..	55.6	34	69.7	.31	.30	55.6	53	75.4	.33	.34
New Orleans.	77.6	19	83.6	.80	.72	74.5	30	87.3	.69	.75
New York...	61.6	49	74.1	.41	.40	58.3	39	67.9	.33	.31
Philadelphia .	59.6	35	68.3	.35	.35	61.4	54	75.5	.41	.38
Pittsburgh...	55.2	37	64.8	.29	.24	59.9	67	69.0	.36	.33
Portland, Ore.	59.7	40	75.0	.39	.37	52.1	24	82.0	.32	.31
Providence...	60.3	37	79.4	.42	.41	55.5	43	68.6	.31	.28
Richmond...	63.5	70	75.9	.45	.41	61.9	50	69.6	.39	.37
St. Louis....	64.2	48	64.1	.39	.32	60.9	38	73.2	.40	.39
St. Paul.....	58.8	48	65.4	.32	.29	49.3	47	83.3	.29	.24
San Francisco	65.5	40	74.5	.47	.42	63.6	38	68.4	.41	.33
Seattle......	54.2	26	86.1	.37	.37	50.9	32	83.2	.31	.31
Spokane.....	56.1	36	65.7	.30	.34	47.7	42	68.4	.23	.22
Toledo......	57.6	58	70.4	.33	.32	55.3	48	74.5	.33	.32
Washington..	58.8	30	74.9	.38	.30	60.9	62	78.2	.42	.36

Cities	Part 10 20–29 days after onset					Part 11 30–39 days after onset				
	Mean temperature	Inter-diurnal change of tempera ture	Relative humidity	Estimated absolute humidity	Absolute humidity at noon	Mean temperature	Inter-diurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany......	52.7	44	79.2	.31	.30	49.8	40	76.3	.27	.30
Baltimore....	59.2	57	63.8	.32	.30	62.1	38	78.2	.44	.40
Birmingham .	66.8	36	82.2	.55	.53	64.0	40	82.3	.50	.38
Boston......	57.2	45	73.0	.34	.41	55.7	47	68.6	.31	.35
Buffalo......	50.3	52	80.0	.30	.29	56.1	44	80.3	.36	.37
Cambridge...	55.3	44	70.2	.31	.29	58.9	46	83.6	.42	.34
Chicago.....	58.4	64	69.7	.35	.34	53.2	48	78.0	.32	.32
Cleveland....	55.3	37	72.1	.33	.33	47.5	47	74.1	.25	.23
Columbus....	59.0	34	75.2	.38	.31	47.3	42	72.1	.24	.25
Dayton......	50.7	52	77.1	.29	.29	47.7	40	72.3	.24	.22
Denver......	46.9	44	69.2	.22	.18	45.4	65	61.8	.19	.17
Fall River...	55.7	53	75.3	.35	.31	51.1	31	65.1	.25	.19
Grand Rapids	47.1	52	80.2	.27	.28	45.8	41	75.9	.24	.24
Indianapolis..	57.3	40	74.4	.35	.35	55.2	38	83.8	.37	.37
Kansas City..	53.7	36	76.5	.32	.29	54.4	64	71.4	.30	.30
Los Angeles..	67.8	16	63.4	.44	.33	67.6	42	55.8	.38	.27
Louisville....	60.5	42	78.1	.41	.41	50.5	42	67.4	.25	.26
Milwaukee...	57.1	76	67.8	.31	.32	48.4	45	83.9	.29	.28
Minneapolis..	55.6	60	65.4	.30	.24	40.0	37	81.9	.20	.21
Nashville....	62.9	32	84.7	.49	.46	52.4	42	69.1	.27	.28
Newark.....	56.1	41	67.7	.31	.29	60.9	31	79.4	.43	.43
New Haven..	53.0	41	71.9	.29	.30	58.9	30	84.1	.42	.43
New Orleans.	72.3	20	86.0	.69	.65	67.0	50	78.7	.53	.50
New York....	59.2	59	67.9	.34	.33	53.7	30	61.7	.25	.24
Philadelphia .	58.5	49	77.0	.37	.32	62.9	35	88.4	.51	.49
Pittsburgh...	56.2	42	68.4	.30	.29	59.0	39	77.8	.39	.38
Portland, Ore.	52.7	14	86.2	.34	.31	47.9	32	89.4	.30	.27
Providence...	55.7	53	75.3	.33	.31	51.1	31	65.1	.24	.19
Richmond...	59.9	46	77.0	.41	.36	54.5	39	72.2	.31	.30
St. Louis....	54.6	60	67.3	.28	.26	52.5	40	68.1	.27	.25
St. Paul.....	59.4	34	83.3	.21	.22	43.7	66	80.8	.23	.25
San Francisco	61.3	36	75.9	.40	.37	57.2	19	74.5	.35	.32
Seattle......	49.8	30	87.1	.31	.31	46.3	26	83.7	.26	.26
Spokane.....	45.7	36	71.5	.23	.23	43.1	18	78.1	.22	.23
Toledo......	48.8	42	80.3	.28	.29	46.6	38	73.9	.24	.23
Washington..	58.7	54	66.8	.34	.31	62.9	46	75.2	.44	.41

TABLE XIII

Part 12

Cities	40–49 days after onset of epidemic				
	Mean temperature	Interdiurnal change of temperature	Relative humidity	Estimated absolute humidity	Absolute humidity at noon
Albany	44.0	33	73.7	.22	.22
Baltimore	49.8	46	65.7	.24	.21
Birmingham	56.3	36	67.4	.29	.26
Boston	52.1	36	76.6	.30	.29
Buffalo	47.0	45	69.8	.23	.24
Cambridge	46.6	45	76.4	.23	.24
Chicago	48.6	37	71.2	.25	.26
Cleveland	48.3	38	69.5	.24	.25
Columbus	48.2	39	71.2	.24	.23
Dayton	42.0	44	78.4	.21	.23
Denver	44.1	48	53.7	.16	.15
Fall River	56.1	53	82.5	.38	.41
Grand Rapids	41.3	41	79.1	.21	.22
Indianapolis	48.0	53	71.0	.24	.22
Kansas City	50.8	42	68.6	.25	.24
Los Angeles	63.7	34	57.6	.35	.27
Louisville	51.9	44	65.9	.26	.24
Milwaukee	46.1	43	78.5	.24	.26
Minneapolis	42.9	47	82.0	.23	.25
Nashville	52.4	51	69.4	.27	.28
Newark	48.6	43	67.8	.24	.22
New Haven	46.6	31	74.8	.23	.23
New Orleans	65.7	36	78.7	.57	.50
New York	59.2	40	79.9	.41	.41
Philadelphia	50.0	37	76.7	.28	.28
Pittsburgh	47.6	49	73.4	.24	.23
Portland, Ore.	46.9	31	82.8	.27	.24
Providence	56.1	53	82.5	.31	.41
Richmond	51.7	49	75.0	.29	.29
St. Louis	42.2	37	71.1	.20	.22
St. Paul	35.6	36	81.0	.17	.20
San Francisco	55.6	17	81.2	.36	.34
Seattle	46.5	37	74.7	.23	.23
Spokane	37.2	24	72.5	.16	.17
Toledo	42.6	42	76.5	.21	.23
Washington	49.0	50	70.0	.25	.21

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APPARATUS USED IN HIGHWAY RESEARCH PRODUCTS IN THE UNITED STATES

Results of Census by

Advisory Board on Highway Research, Division of Engineering,
National Research Council, in Cooperation with the
Bureau of Public Roads, United States
Department of Agriculture

By

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FOREWORD

After considerable time and effort have been expended in the development of a special instrument or device for highway research, it is often found by trial to be unsuited for the accomplishment of desired results, and must either be remodeled or discarded entirely. The same type of instrumental difficulty is many times encountered by different investigators working on similar problems. While the expenditure for salaries and materials in the development of unsatisfactory devices may be very small, the delay in securing data is unfortunate. Researches into the effects of unknown forces are necessarily accompanied by delays and disappointments, which, however, can be minimized by knowledge of the experience of fellow-workers.

The purpose of this report on Highway Research Apparatus is to assist in establishing a fund of common knowledge on the part of investigators of similar problems. The intention is not to set forth the advantages or disadvantages of the various devices, nor to give the degree of success attained in their use, but rather to describe only the principle and construction of each device and the purpose for which it was designed. For seekers after additional information, the names of organizations and individuals who have had experience with the various devices and instruments are given.

Detailed descriptions of standard laboratory equipment are not given. Apparatus for determining such factors as influence the design of motor vehicles have not been listed, since, by agreement between the Committee on Economic Theory of Highway Improvement of the Advisory Board on Highway Research and the Society of Automotive Engineers, all research of this character has been delegated to the latter organization.

The information on highway research apparatus was secured from questionnaires sent to all investigators listed in National Research Council Bulletin No. 21, Results of Census of Highway Research Projects in the United States. Notification of the existence of apparatus not listed in this circular will be appreciated.

The organization and activities of the Advisory Board on Highway Research are described in National Research Council Bulletin Number 32, entitled Proceedings of the Second Annual Meeting of the Advisory Board on Highway Research, Division of Engineering, National Research Council.

William Kendrick Hatt,
Director, Advisory Board.

APPARATUS USED IN HIGHWAY RESEARCH INVESTIGATIONS IN THE UNITED STATES

Apparatus is arranged alphabetically by states, the District of Columbia being treated as a state.

GROUP I. APPARATUS USED IN INVESTIGATIONS IN THE FIELD OF ECONOMIC THEORY

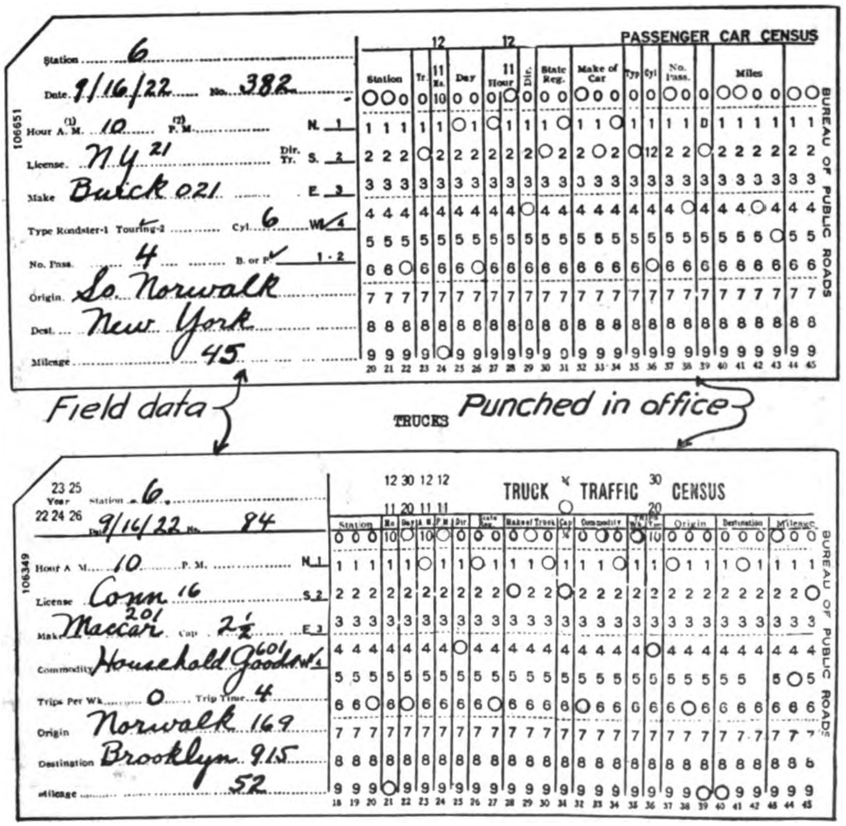
1. *Determination of Character and Intensity of Traffic.*

District of Columbia: U. S. Bureau of Public Roads.

TRAFFIC CENSUS TABULATING CARDS

On these cards can be recorded, in the field, details of both passenger and truck service, concerning type and condition of car and equipment, number of passengers, origin and destination, mileage,

PASSENGER CARS



PASSENGER CAR CENSUS

106651
Station 6
Date 9/16/22 No. 382
Hour (1) A. M. 10 (2) P. M. N. 1
License NY 21 Dir. Tr. S. 2
Make Buick 021 E. 3
Type Roadster-1 Touring-2 Cyl. 6 W. 4
No. Pass. 4 B. or P. 1 · 2
Origin So. Norwalk
Dest. New York
Mileage 45

TRUCKS

TRUCK TRAFFIC CENSUS

106349
Year Station 6
Date 9/16/22 No. 84
Hour A. M. 10 P. M. N 1
License Conn 16 S 2
Make Maccar 201 Cap 2½ E 3
Commodity Household Goods 601 W 4
Trips Per Wk. 0 Trip Time 4
Origin Norwalk 169
Destination Brooklyn 915
Mileage 52

FIGURE 1.—TRAFFIC CENSUS TABULATING CARDS

pleasure or business; and, in the case of trucks, additional information as to the commodity carried and weights on both front and rear axles. One card is used for each unit of traffic. Information secured in the field is recorded on the left side of the card, as shown in the accompanying illustration (Figure 1), after which the cards are sent to the U. S. Bureau of Public Roads, Washington, D. C., where the information indicated by code figures is punched on the right side. Compilation of the data is accomplished by means of special tabulating machines.

Used by State Highway Departments of California, Connecticut, and Massachusetts in traffic studies.

Designed by U. S. Bureau of Public Roads.

AUTOMATIC SCALE AND TRAFFIC COUNTER

This apparatus, Figure 2, consists essentially of a steel trough 10 feet long, containing a piece of fire hose 9 feet long by 2 inches in diameter, on which rests a plunger attached to a platform, over which traffic passes. As shown in the sectional drawing, Figure 3, the trough is made of two 6-inch channels (A) connected to a base ¾-inch by 14-inch plate (B), and the plunger consists of a 6-inch

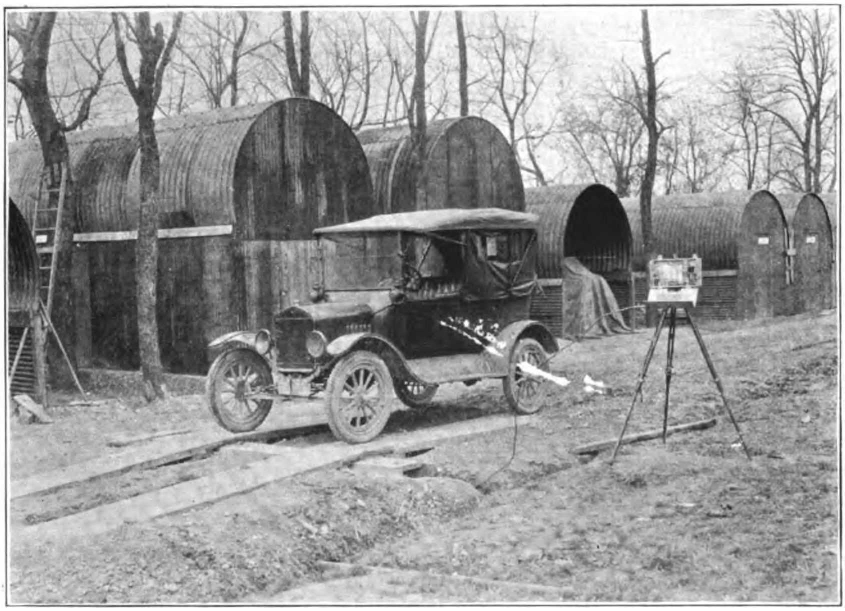


FIGURE 2.—AUTOMATIC SCALE AND TRAFFIC COUNTER, ARLINGTON EXPERIMENTAL FARM

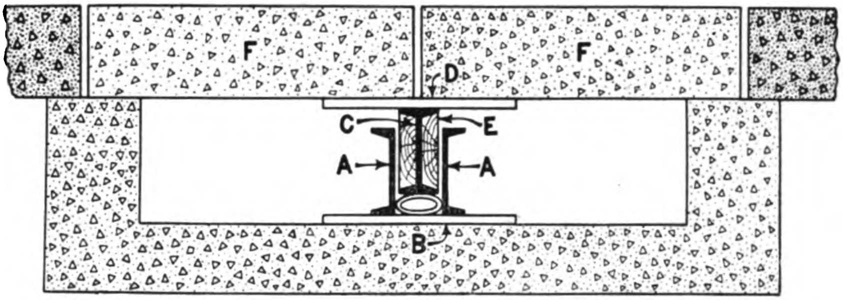
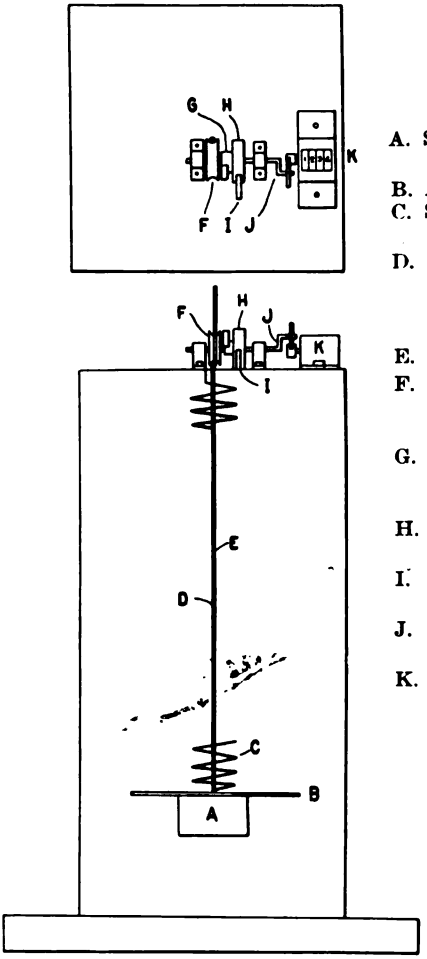


FIGURE 3.—ARRANGEMENT OF TRAFFIC COUNTER IN A ROAD



A. Seismograph weight.
B. Air damping disc.
C. Steel wire helical spring.
D. Vertical rod for actuating counter.
ends of rod D.
E. Linen cord tied to
F. Grooved pulley with friction ratchet.
G. Small pulley fast on shaft, driven by ratchet.
H. Holding pulley fast on shaft.
I. Friction pawl for pulley H.
J. Crank driving counter.
K. Veeder revolution counter.

FIGURE 4.—LOCKWOOD ROUGHNESS INTEGRATOR

I-beam (C) attached to a ¾-inch by 14-inch plate (D). Wooden guides (E) bolted to the I-beam prevent horizontal movement of the plunger. The trough is set in a concrete box so that the top of the platform is approximately flush with the bottom of the road surface. Traffic passes over concrete slabs (F), which rest on the plunger. The hose, filled with heavy oil, is sealed at one end, while at the other it is connected to a recording device[1] by means of a flexible tube. A record of pressures exerted on the oil in the hose is thus secured. The recording paper is automatically moved forward a short distance every time a pressure is recorded. The weights of the front and rear wheels, as well as the number of vehicles passing, are recorded. The passage of 4,800 traffic units can be recorded on one roll of paper. Before being used on a road, the apparatus is calibrated with static loads.

The apparatus installed in the Washington-Baltimore boulevard is used for traffic counts.

Developed and constructed by the U. S. Bureau of Public Roads.

2. Determination of Operating Cost of Vehicles.

Connecticut: Yale University.

LOCKWOOD ROUGHNESS INTEGRATOR

The device, shown diagramically in Figure 4, consists of a seismograph weight (A) suspended by a steel wire helical spring (C). A rod connected to the weight is so arranged that its movement in one direction only is recorded by a Veeder revolution counter (K), to which the motion is transmitted by means of specially designed pulleys and shafts. When attached to any part of a motor vehicle, it registers the summation of vertical movements which occur during any definite period of operation. The result is expressed in amount of vertical variation per unit of horizontal distance traversed by the vehicle.

Used for determining relative roughness of various road and street surfaces in Connecticut.

Developed by E. H. Lockwood, Yale University.

District of Columbia: U. S. Bureau of Public Roads.

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[1] In this instrument the recording device is a trainagraph manufactured by the American Steam Gage & Valve Manufacturing Company, Boston, Mass.

TRACTOGRAPH

This apparatus consists essentially of a spring so mounted on the tongue of a wagon that it receives the force of the pull exerted by the horses on the doubletrees. The variation in traction as indicated by change in spring length is recorded on paper carried by a cylinder. The paper movement is proportional to the distance traveled by the wagon. Calibration of the apparatus consists of determining spring compressions which accompany definite pressures.

Used first in a road exhibit at the Cotton States and International Exposition in Atlanta, Ga., in 1895. Later employed in investigations on the effect of different types of surfaces, as well as different tire widths on the force required to move definite loads.

Developed by U. S. Office of Road Inquiry. See Bulletin No. 20, U. S. Department of Agriculture, Office of Road Inquiry, Tractive Tests, by Samuel T. Neely.

RECORDING DYNAMOMETER, WAGON TYPE

The dynamometer (Figure 5) is suspended rigidly from the bed of the wagon. Two coil springs, through which the power is trans-

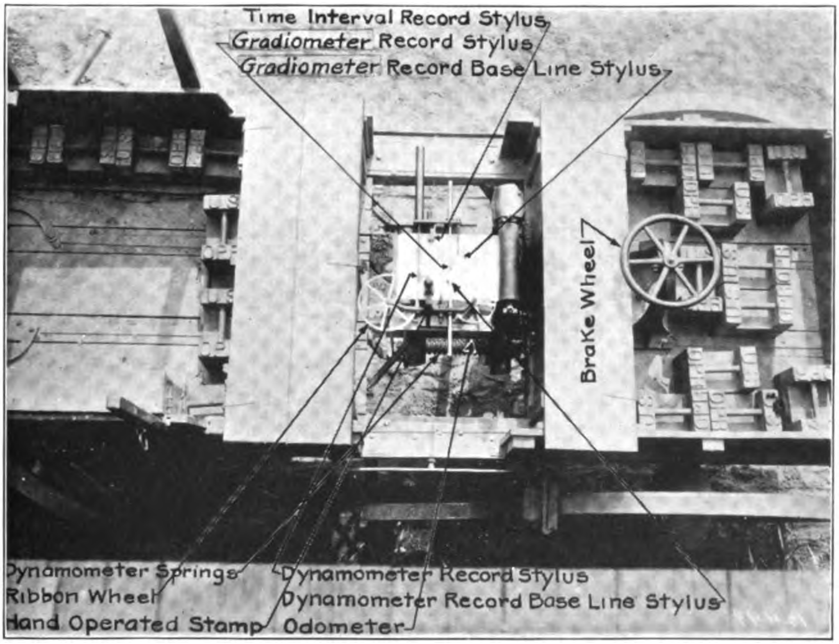
Time Interval Record Stylus
Gradiometer Record Stylus
Gradiometer Record Base Line Stylus
Brake Wheel
Dynamometer Springs
Ribbon Wheel
Hand Operated Stamp
Dynamometer Record Stylus
Dynamometer Record Base Line Stylus
Odometer

FIGURE 5.—RECORDING DYNAMOMETER, WAGON TYPE

mitted, are in the line of draft from the tongue. The tongue slides freely in roller-bearing guides, and is attached to the traction rod of the dynamometer. As this traction rod is moved forward by the pull on the tongue, the springs are compressed an amount corresponding to the draft exerted. This compression is transmitted through a rack and gear to a ribbon wheel, and, through a steel ribbon, permits the record point to be moved by a coil spring which is in tension. The record points are brass styli, mounted so as to allow slight vertical movement, with constant pressure on the record paper. By this arrangement of rack, gear, ribbon wheel, and spring, all effects of vibration are eliminated without decreasing the accuracy of the mechanism. Sensitized paper, 10 inches wide and some hundred yards in length, is fed through rolls driven by a sprocket-wheel on the hub of one of the rear wheels of the wagon. An odometer, interposed in the gearing, shows the distance traveled. The ratio of paper movement to road travel is 1:264; 240 inches of record representing one mile of road distance.

The machine is equipped with a recording gradiometer of the pendulum type, which approximately determines grades, and also a time-interval clock, which records 15-second intervals. For location of natural landmarks, fractions of miles traveled, etc., a hand-operated fixed-number stamp is used, the explanatory notation being recorded by the observer. The draft on towed vehicles can be obtained by reversing the dynamometer.

The wagon is equipped with eight sets of wheels, ranging from 1⅝ to 6 inches of tire width. The brake on the wagon is under control of the observer. Variation in load is obtained by the use of 100-pound weights.

Used for determining the efficiency of street-cleaning apparatus, percentage of improvement of post-road projects, effect of width of tires, and resistance of various road surfaces to traction on steel-tired wheels.

Designed by Kansas State Agricultural College. Modified and adapted by U. S. Bureau of Public Roads.

Constructed by Studebaker Wagon Co. and U. S. Bureau of Public Roads.

TORSION DYNAMOMETER, AUTOMOBILE TYPE

The torsion dynamometer (Figure 6), installed on the propeller shaft of a motor vehicle, is enclosed in an oil-tight casing, supported by the torque rods of the car or truck. Universal joint connections

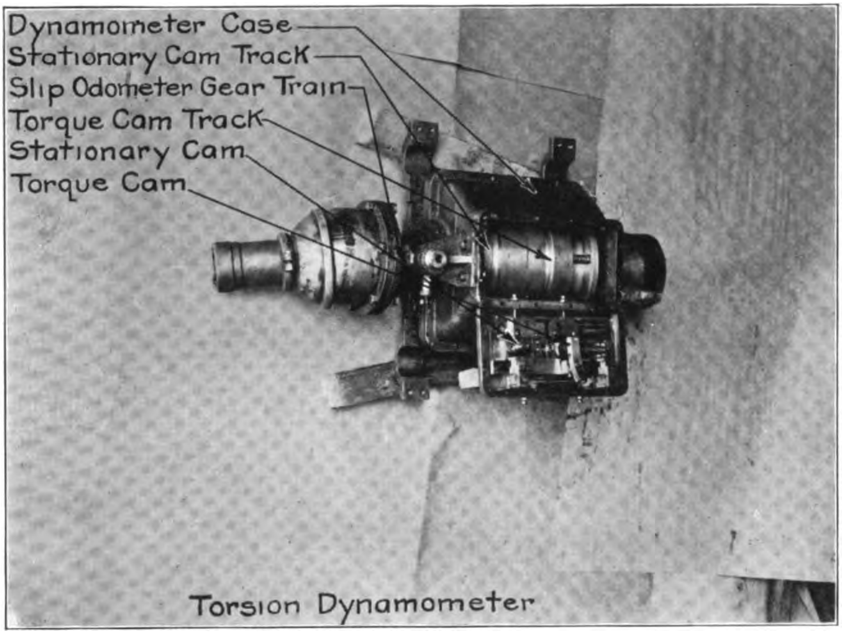

FIGURE 6

with the propeller shaft and the differential housing prevent misalignment of the apparatus.

The dynamometer consists of two flanged couplings, connected by a spiral spring. The face of the front coupling, which carries an annular cam track, has two helical surfaces 180 degrees apart, which are reversed to two helical surfaces on a sliding collar attached to the rear flange coupling. An annular cam track carried by this sliding collar translates, by means of a rack and pinion and a freely revolving shaft, the distortion of the spiral spring to the torque record stylus.

The recording apparatus (Figure 7) consists essentially of two sets of rolls driven by a flexible shaft geared to the front wheel. Surface-coated paper, 10 inches wide and some hundred yards in length, is used. The ratio of paper movement to road travel is 1:264; 240 inches of record representing a torque record of one mile of road distance.

Two odometers are used, one being attached to the front wheel gearing and the other to the propeller shaft in front of the torsion dynamometer. The slippage of the rear wheels is shown by difference in odometer readings.

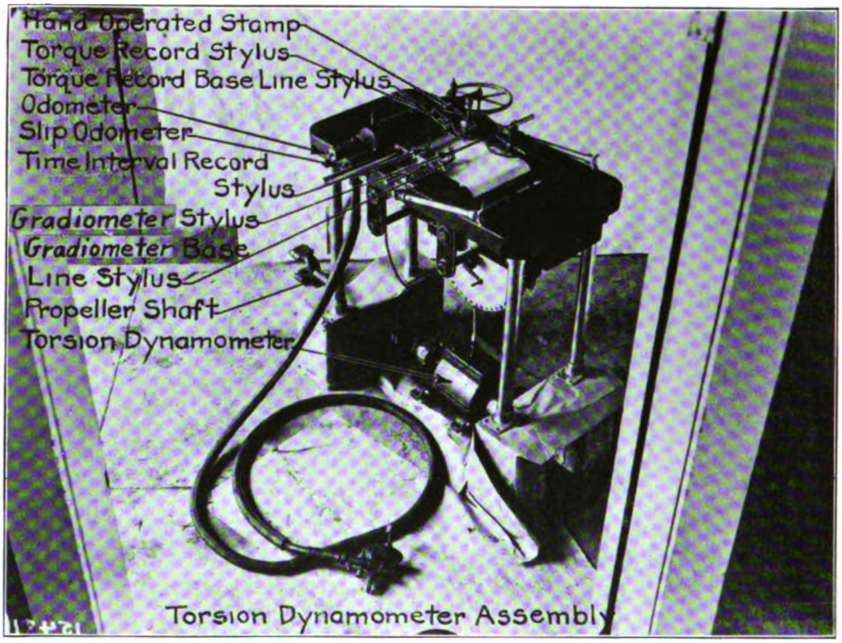
Hand Operated Stamp
Torque Record Stylus
Torque Record Base Line Stylus
Odometer
Slip Odometer
Time Interval Record Stylus
Gradiometer Stylus
Gradiometer Base Line Stylus
Propeller Shaft
Torsion Dynamometer
Torsion Dynamometer Assembly

FIGURE 7.—TORSION DYNAMOMETER RECORDING APPARATUS

The machine is equipped with a recording gradiometer of the pendulum type, which approximately determines grades, and also with a time-interval clock which records 15-second intervals. For location of natural landmarks, fractions of miles traveled, etc., a hand-operated fixed-number stamp is used, the explanatory notation being recorded by the observer.

Contemplated use in determining resistance of various road surfaces to traction of rubber-tired, self-propelling vehicles.

Designed and constructed by the U. S. Bureau of Public Roads.

PROFILOMETER FOR MEASURING ROUGHNESS OF ROAD SURFACES

The apparatus (Figure 8) consists of a straight edge (A) or track 24 feet long, and a recording device (B) which, when drawn over the track, records accurately and autographically the profile of the pavement beneath. The track, as used on the Bates road in Illinois, is supported by three bicycle wheels, and consists of two wooden trusses 24 feet long by 20 inches high with a 3-inch space between them. Four turnscrews (C), two at each end, permit leveling the track at each set-up, while a piano wire under constant tension, stretched from end to end, gives a datum for detecting any sag in the track.

The recording apparatus consists of an American strainagraph[2], whose pen arm is connected by a rod with a brass wheel (D) resting on the pavement surface. This allows surface irregularities passed over by the small wheel to be traced on the recording paper. The instrument, which is mounted on a wooden platform carried by four wheels, each 2½ inches in diameter and 2 inches wide, is kept aligned by two guide wheels, which run in the 3-inch space between the trusses.

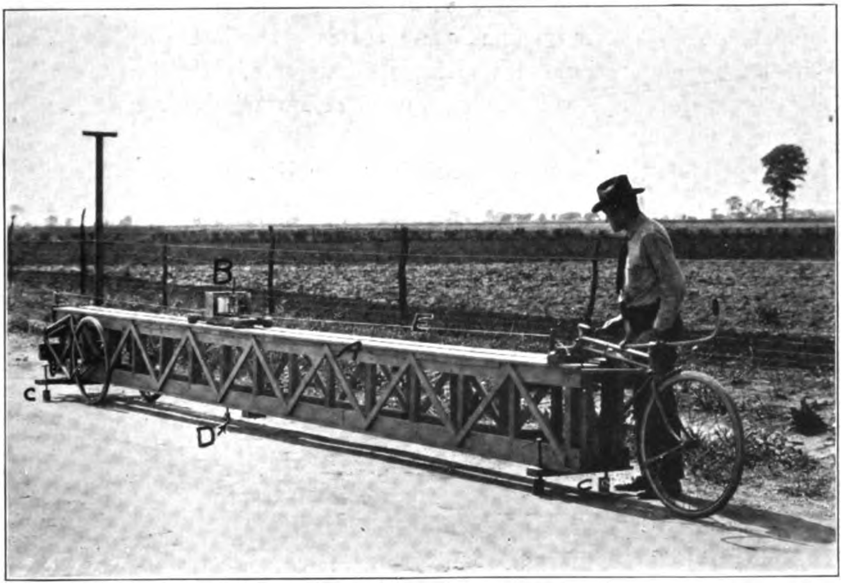

FIGURE 8.—PROFILOMETER

For drawing the recording device over the track, a wire cable attached to each end of the platform and passing over a pulley at each end of the trusses is used. The pulley at one end is operated by a crank.

The summation of the vertical ordinates of the surface profile is obtained by means of a special attachment consisting of a fiber strip ½ inch wide by 6 inches long, which receives the pen arm

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[2] The American strainagraph, manufactured by the American Steam Gage & Valve Manufacturing Company, Boston, Mass., was used by the U. S. Shipping Board in investigations of stresses in concrete ships.

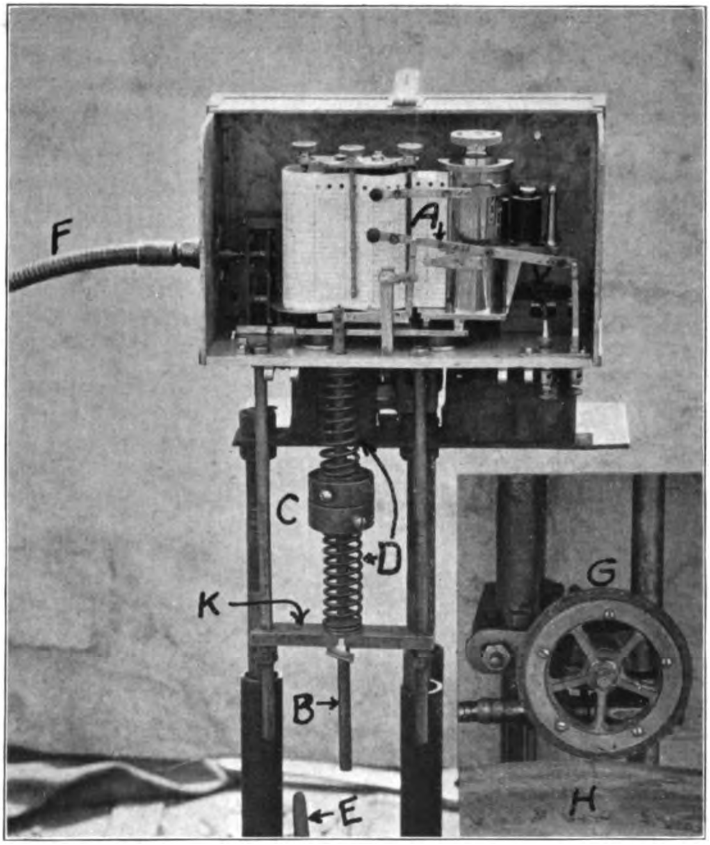


FIGURE 10.—ACCELEROMETER; INSERT, DRIVING WHEEL

the guide bar (K) either upward or downward, the compression of the springs can be varied. By means of this adjustment the instrument becomes adaptable for securing records on surfaces of varying degrees of roughness. When records are not desired, the movement of the pen is prevented by tightening the set screw in the guide bar, and the paper movement is stopped by raising the driving wheel by means of a small rod, the top of which (E) is shown at the bottom of the illustration.

The theory of this device is simple. The record will be a straight line unless the weight in the instrument changes its position with respect to the axle. Any vertical acceleration, however, will cause the weight and consequently the pen to vary from a straight line. The greater the acceleration the greater will be the variation from a straight line. This variation is a measure of the force which causes it, and the force corresponding to any particular variation can be determined by calibrating the springs. Knowing this force, and the mass of the wheel and axle, it will be possible to compute the corresponding impact.

Used in co-operation with the Illinois Division of Highways on the Bates experimental road in an investigation of the effect of road surface irregularities on motor truck wheels.

Devised by the U. S. Bureau of Public Roads, and constructed at the Bureau of Tests, Illinois Division of Highways, Springfield, Illinois.

Iowa: Experiment Station, Iowa State College.

DAVIDSON DYNAMOMETER

This apparatus is a spring-type dynamometer equipped with a recording device that plots a curve showing the variation in draw-bar pull and mechanically integrates the area under the curve.

Designed by Prof. J. B. Davidson, Department of Agricultural Engineering, Iowa State College.

First used on tractive resistance investigations carried on under the direction of Professor Davidson in California and Iowa on experiments of the draft of implements and tractive resistance of vehicles. The instrument has been in factory production for several years.

GULLEY DYNAMOMETER

This apparatus consists of a pressure cylinder which is attached to the draw bar between the towing vehicle and the one under test, and a recording device which plots a curve of the draw-bar pull. The connection between the pressure cylinder and the recording mechanism is a flexible pressure tube. It was thought that the column of oil in the tube and pressure cylinder would serve to damp out some of the impact effects.

For descriptions and use of the Davidson and Gulley dynamometers see Bulletin 64, Iowa State College of Agriculture and Mechanical Arts, "Resistance to the Translation of Motor Vehicles," by T. R. Agg.

FLOWMETER FOR MEASURING FUEL CONSUMPTION OF MOTOR VEHICLES

The flowmeter is in principle a piezometer so arranged as to have a constant pressure head. The velocity head, which varies with the

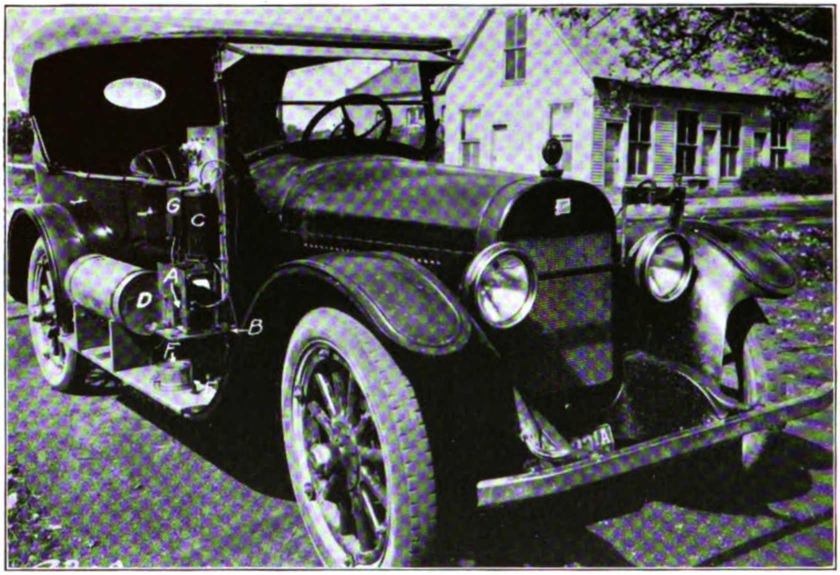


FIGURE 11.—FLOWMETER

quantity of gasoline flowing, is measured by means of a calibrated diaphragm, the movement of which is recorded by an electric spark punching holes in the recording paper.

In Figure 11 the diaphragm is shown at A and the needle valve at B. The vacuum tank at C is used to give nearly constant head and the spare tank at D affords a check on the records. The spare tank may be dispensed with in most cases and connection made to the supply tank on the vehicle. The cable of a taximeter drive (E) is used to operate the paper rolls, and F is a clock arranged to close a circuit momentarily and punch a hole in the paper every ten seconds. The distance between the time marks on the record paper is proportional to the vehicle speed and furnishes the data for a speed curve for the run. A spark coil (G) provides the high-tension current for punching the record paper.

The pilot tube shown over the head-light on the car is connected to an air-speed indicator on the instrument board of the car, and enables the observer to eliminate records which may have been influenced by the wind. The paper upon which the records are made is drawn through the recording device by means of rollers geared to the front wheel of the vehicle, so that the paper travel bears a fixed ratio to the wheel travel. For passenger vehicles the paper moves approximately ½ inch per 100 feet of vehicle travel. For trucks the paper travel is somewhat less.

In using the meter, the paper travel is first determined by calibration runs over a measured course. The needle valve is then set so as to give a record about 1½ inches high when the vehicle is operating so as to use the maximum amount of gasoline. The meter is then calibrated and is ready for use.

There are two sources of error in the instrument, both of which are small: (*a*) errors caused by fluctuations of the flow of gasoline, due to the operation of the float valve in the carburetor; (*b*) variations of the pressure head, due to the fluctuations of the gasoline level in the vacuum tank. The accuracy of the meter has been tested in various ways, and for ordinary operating conditions the maximum error is about 5 per cent and the average error about 2 per cent.

Used in investigations of resistance to the translation of motor vehicles, Iowa State College.

Designed and constructed by the Engineering Experiment Station, Iowa State College, Ames, Iowa.

See "Economic Theory of Highway Grades," by T. R. Agg, Engineering News-Record, Vol. 90, No. 2, Jan. 11, 1923.

SPACE-TIME RECORDER

The instrument consists of a paper feed that moves the paper along at a fixed ratio to the distance the vehicle travels and a pen line to indicate time intervals. The paper feed is driven by a speedometer cable connected to a gear on the front wheel. The time line is broken every one-half second by a pen actuated by a clock mechanism.

The acceleration can be computed accurately from the ratio of distance of paper travel to time.

Used in investigations of resistance to the translation of motor vehicles, Iowa State College.

Designed and constructed by Engineering Experiment Station, Iowa State College, Ames, Iowa.

See Bulletin 64, Iowa State College of Agriculture and Mechanical Arts, "Resistance to the Translation of Motor Vehicles," by T. R. Agg.

Massachusetts: Quartermaster Tractive Resistance of Roads Research, Massachusetts Institute of Technology, Cambridge, Massachusetts.

WIMPERIS ACCELEROMETER WITH LOCOMOTIVE RECORDING ATTACHMENT

The recording attachment consists of a tripod to facilitate mounting the instrument in a vehicle, with dry-cell battery and recording device properly attached. The rolls which feed the adding machine paper over the accelerometer needle are driven by the vehicle's speedometer cable. Both half-second time intervals and instantaneous needle positions are recorded by electric sparks, which perforate the paper. This gives speed for the time-distance relation, and also a value for checking the accuracy of the gross, level-road tractive resistance for coasting vehicles, as indicated by the accelerometer needle.

Used November, 1921, to May, 1922, in Connecticut and Massachusetts by the Quartermaster Tractive Resistance of Roads Research Party.

See "Application of Power to Road Transport," by H. E. Wimperis, in S. A. E. Journal for 1921, pages 30–36.

The Wimperis accelerometer is manufactured by Elliott Brothers, London, England, and the recording device by the Locomobile Company, Bridgeport, Conn.

MASSACHUSETTS TRACTIVE RESISTANCE RECORDER

This apparatus consists of a mercury accelerometer, with an automatic recording device. Record is made by electric spark perforation of record paper. The instrument registers gross, level-road tractive resistance on level or inclined profiles, also speed (by time-distance relation) and other pertinent data. It is readily adaptable to use with a hydrostatic-pressure dynamometer for towing tests. Provision has been made for the addition of such other data records as may be found desirable.

The Massachusetts tractive resistance recorder is the property of the Department of Public Works, Commonwealth of Massachusetts, and is now loaned to the University of Michigan for the use of the University and the Michigan State Highway Department.

Used in the summer of 1922 at Massachusetts Institute of Technology, and in the vicinity of Boston, Massachusetts.

Adapted from the liquid accelerometer idea of the Bureau of Standards, and the electric recording idea of the Locomobile Company to the problem of this research party by Mr. William O. Tait, Automotive Engineer, Bureau of Public Roads, and Major Mark L. Ireland, Q. M. C., U. S. A., Director of Research.

Pamphlet description (typewritten) filed with Department of Public Works, Commonwealth of Massachusetts, Bureau of Public Roads, Q. M. C., U. S. A., Massachusetts Institute of Technology, Yale University, and Harvard University.

Constructed by Quartermaster Tractive Resistance of Roads Research Party at Massachusetts Institute of Technology.

DRAW-BAR PULL DYNAMOMETER

The instrument consists essentially of a piston and cylinder filled with 600 W. transmission oil and connected with an indicating and pressure gage by flexible metal tubing. The apparatus is so connected between the towing and the towed vehicles that the tension between the two is indicated by the recorded oil pressure.

Used in Michigan State Highway Department investigations of truck performance on grades.

For detailed description, see report of above investigations in University Bulletin, New Series, Vol. XXIV, No. 19, Nov. 4, 1922, College of Engineering, Proceedings of the Eighth Annual Conference on Highway Engineering, held at the University of Michigan, February 13–17, 1922.

GROUP II. APPARATUS USED IN INVESTIGATIONS OF THE STRUCTURAL DESIGN OF ROADS

1. *Subgrade Investigations.*

District of Columbia: U. S. Bureau of Public Roads.

BEARING POWER DETERMINATOR (STATIC LOAD)

This device (Figure 12) for determining the supporting value of soils when subjected to static loads, consists essentially of a brass cylinder (A) and footing (B) so arranged with a tripod that, while vertical movement is allowed, all horizontal movement of the top of the device is eliminated. The loading agency, shot, which is fed into the funnel shown on the top of the tripod, flows through an orifice at a constant rate of speed. The rate of flow of shot is determined by calibration of the orifice. Deformation of the soil under the footing, indicated by the vertical movement of the plunger, is measured by an Ames dial, shown just above the tripod head. Knowing the time of flow of shot, the vertical movement of the plunger, and the area of the footing, the depth of soil penetration for a definite pressure is easily computed.

Used in experiments at the Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Designed and constructed by the U. S. Bureau of Public Roads.

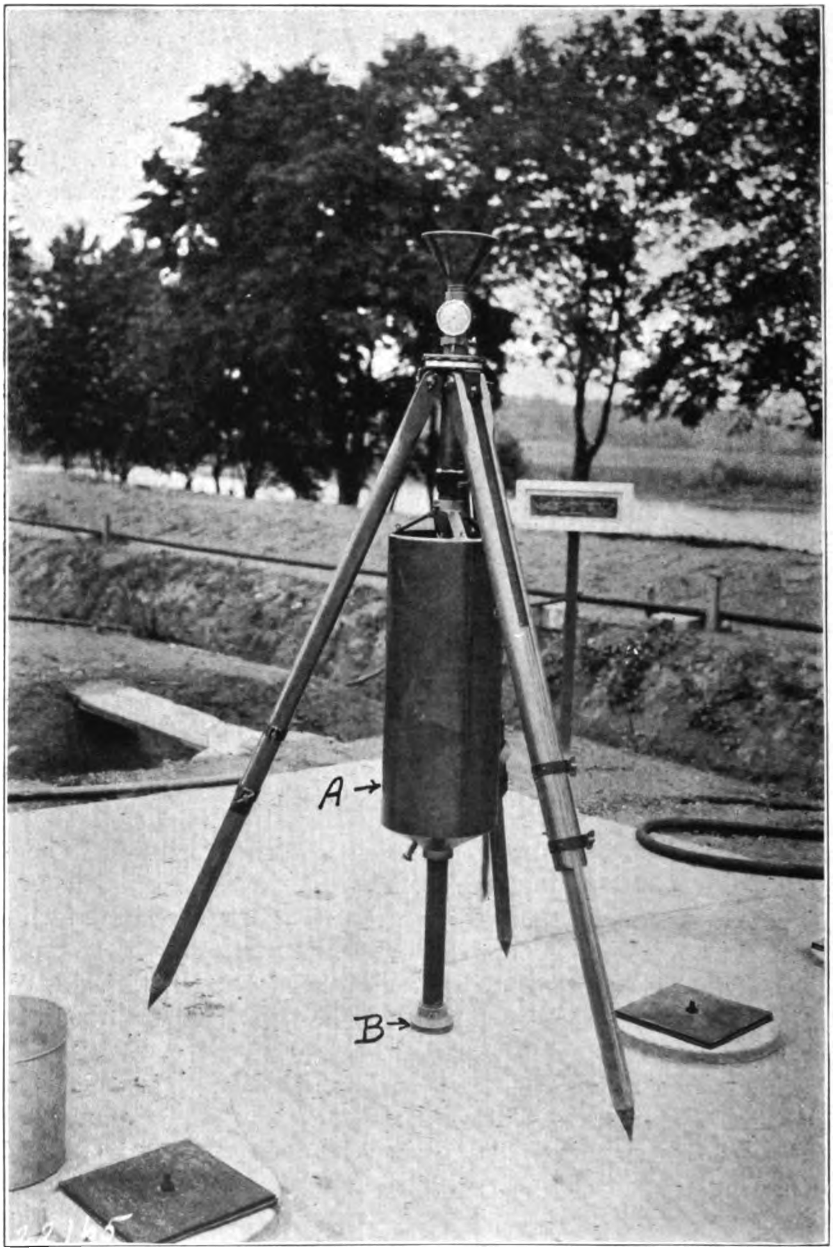


FIGURE 12.—BEARING POWER DETERMINATOR (STATIC LOAD)

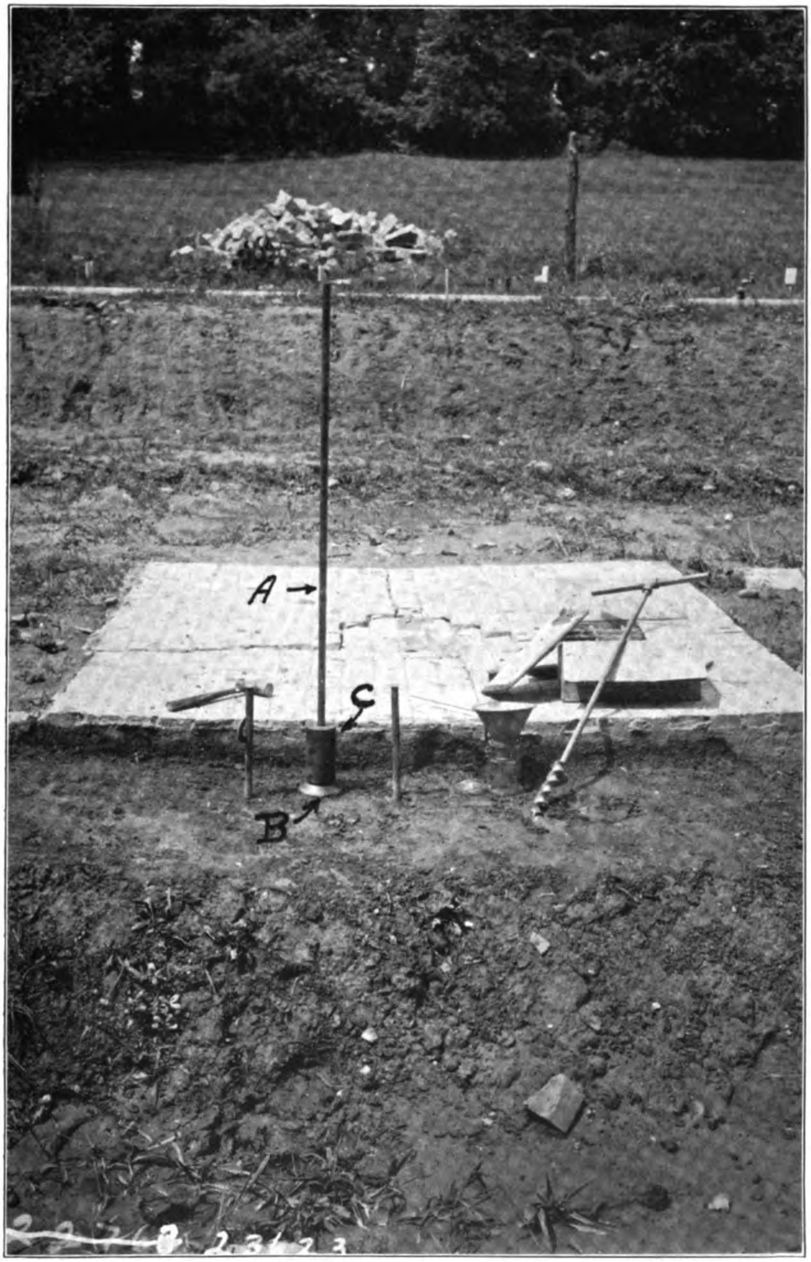


FIGURE 13.—BEARING POWER DETERMINATOR (IMPACT)

BEARING POWER DETERMINATOR (IMPACT)

This device (Figure 13) for determining the resistance of soils to impact, consists essentially of a rod (A) and a footing (B) and a steel cylinder (C), fitted loosely on a rod so that it can be dropped from any height. The footing has an area of about 7 square inches and the cylinder weighs 10 pounds. The difference in the elevation of the rod, before and after a given number of drops of the cylinder from a definite height, is the deformation of the soil. This difference is measured by means of an engineer's scale.

Used in studies of comparative supporting values of subgrades in the Arlington experiments and the Bates road tests.

See Public Roads, Vol. 4, Nos. 5 and 6, September and October, 1921.

Designed by U. S. Bureau of Public Roads.

SUBGRADE CYLINDER FOR DETERMINING SEPARATION BETWEEN SUBGRADE AND SURFACE

This device (Figure 14), which is a modification of the Illinois Subgrade Testing Cylinder (see below). consists of a brass cylinder (A) and plug (B), which can be placed in the pavement during construction, and an Ames dial (C), having a special stem. A thin brass flange (D) is soldered on the bottom of the cylinder to facilitate placement in the pavement during construction. The bottom of the plug is flush with the flange. To measure the separation between the surface and subgrade, the brass plug is removed from the cylinder and the dial is set in its place.

Used in tests of warping of concrete slabs and second series of impact tests at Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Adapted by the U. S. Bureau of Public Roads.

SOIL PRESSURE CELL (FOR MEASURING PRESSURES OF SOILS AND OTHER GRANULAR MATERIALS)

Principles of pressure measurement with this instrument depend upon: (1) The equilibration of the soil pressure with air pressure within a small cell buried at the point where it is desired to determine the pressure; (2) the detection of the instant of equilibration by the breaking of electrical contact within the cell; (3) the measurement of the air pressure within the cell at the instant of equilibration by the use of a sensitive gage.

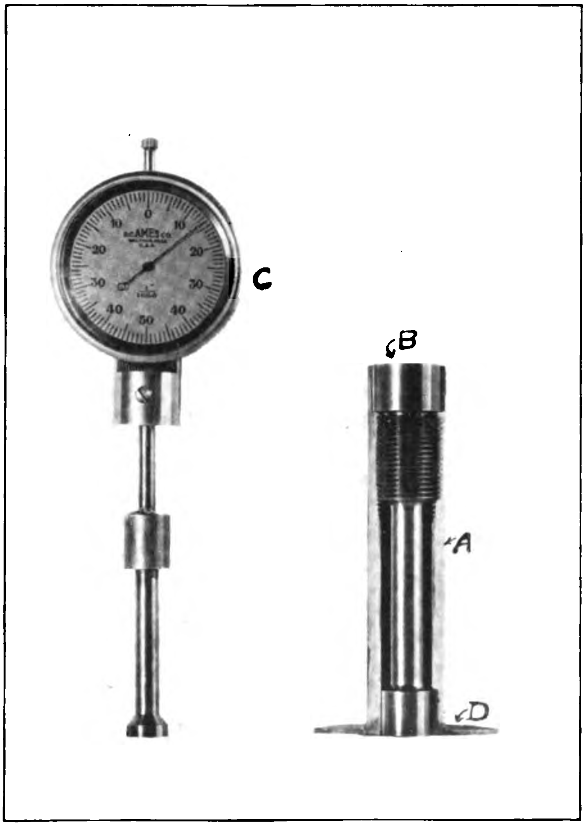
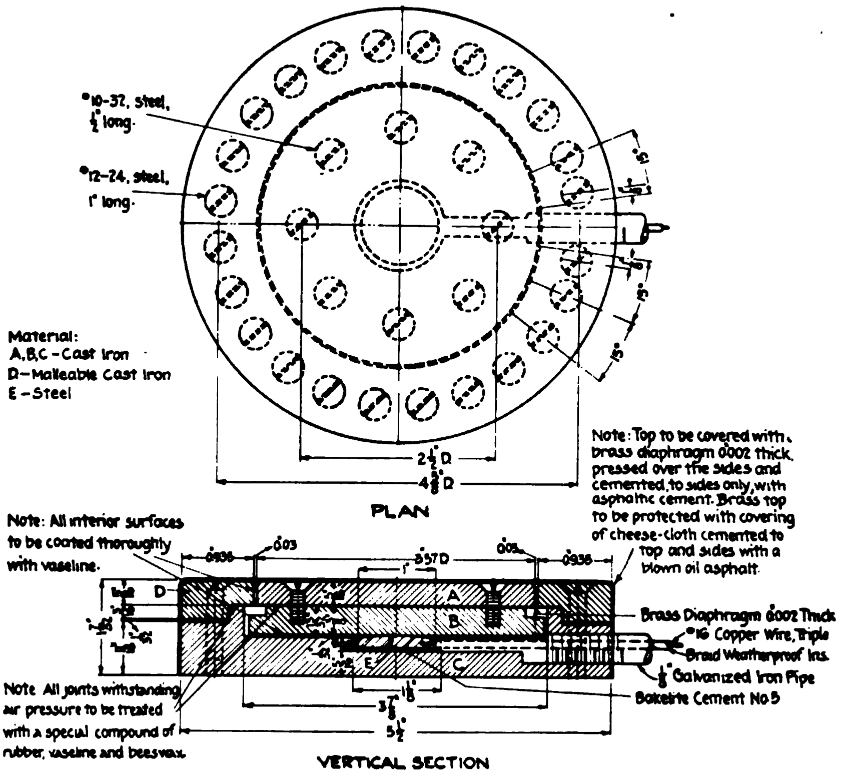


FIGURE 14.—SUBGRADE TESTING CYLINDER

A cross section of the cell as it is used at present is presented in Figure 15, and its construction is shown plainly without further description. When in operation, the movable side of the cell (plan view in Figure 15) is placed in contact with the earth fill in the direction necessary to give the desired component of pressure, horizontal, vertical, or oblique. The ⅛ inch pipe containing an insulated wire is led to any convenient accessible place for taking the measurements. The cell may be at any distance from the pressure recording instrument. When the internal pressure caused by air entering the cell through the pipe just exceeds the soil pressure, contact is broken between B and E. This fact is shown immediately by the extinguishing of a small electric light, and the operator at the indicating instrument at once notes the pressure on the pressure gage. This, for practical purposes, equals the soil pressure.


*10-32, steel, ⅝ long.
*12-24, steel, 1" long.
Material:
A,B,C - Cast Iron
D - Malleable Cast Iron
E - Steel
15°
15°
15°
2¼ D
4⅝ D
PLAN
Note: Top to be covered with a brass diaphragm .0002 thick, pressed over the sides and cemented, to sides only, with asphaltic cement. Brass top to be protected with covering of cheese-cloth cemented to top and sides with a blown oil asphalt.
Note: All interior surfaces to be coated thoroughly with vaseline.
.0935
.003
.8570
1"
.003
.0935
D
A
B
C
E
Brass Diaphragm .0002 Thick
*16 Copper Wire, Triple Braid Weatherproof Ins.
⅛" Galvanized Iron Pipe
Bakelite Cement No 5
Note All joints withstanding air pressure to be treated with a special compound of rubber, vaseline and beeswax.
1⅛"
3⅞"
5½
VERTICAL SECTION

DIAPHRAGM CELL FOR DETERMINING SOIL PRESSURE
U. S. OFFICE OF PUBLIC ROADS AND RURAL ENG'G.
SCALE FULL SIZE
FIGURE 15

The indicating instrument (Figure 16) can be placed in any desired and convenient position, its air and electrical connection being so arranged that but a few seconds are required to shift from one cell to another. A compressed air tank, which may be filled with air by means of a hand pump, is shown at the bottom of the containing box. It is fitted with a rough gage for recording its approximate pressure. Two accurate standard pressure test gages are placed in the line leading to the pressure cell buried in the fill. These appear just above the air tank. One is graduated from 0 to 30 pounds by increments of 0.2 pound; the other reads up to 100 pounds in increments of 1 pound. A dry cell, a switch, and an electric light are the only electrical equipment required. Necessary

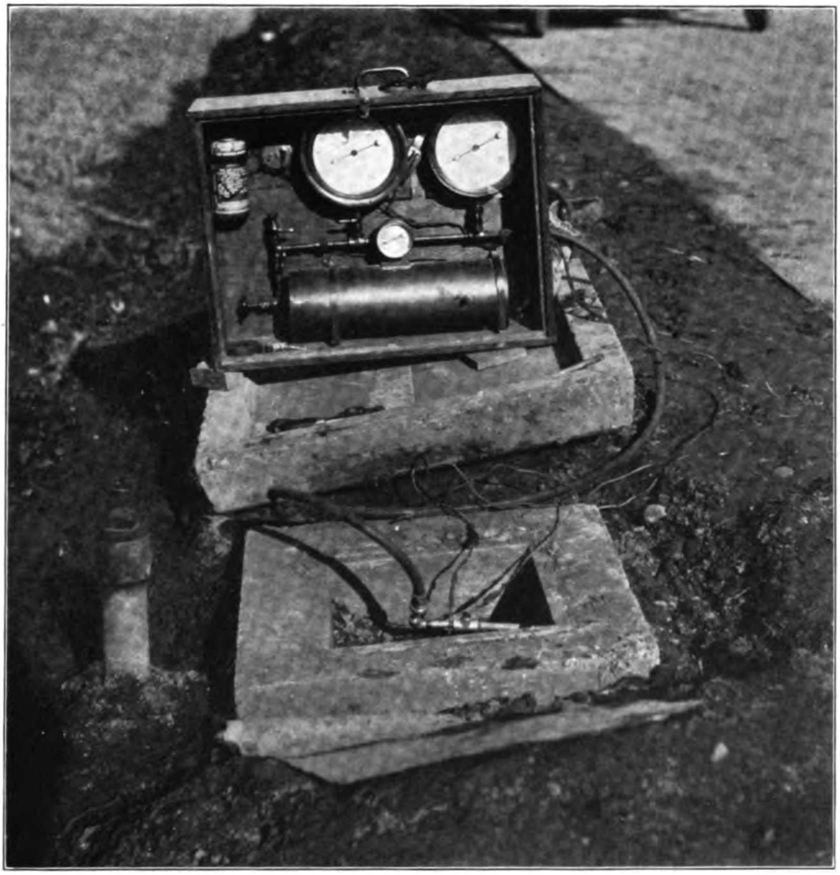


FIGURE 16.—APPARATUS FOR READING PRESSURE ON SOIL PRESSURE CELLS

valves are placed in the air line to enable the operator properly to control the pressure within the pressure cell.

Used for measuring soil pressure against bridge abutments and retaining walls; in pressure distribution experiments, and for obtaining subgrade pressures under experimental roads at Camp Humphreys, Virginia; Bates, Illinois; and Pittsburg, California.

Designed and constructed by U. S. Bureau of Public Roads.

See "An Apparatus for Determining Soil Pressure," by A. T. Goldbeck and E. B. Smith, A. S. T. M. Proceedings, 1916, and "Distribution of Pressures Through Earth Fills," by A. T. Goldbeck, A. S. T. M. Proceedings, 1917.

APPARATUS FOR PRODUCING VIBRATIONS ON SUBGRADES

The soil vibrator (Figure 17), consists essentially of a plunger carried by a lever, whose one end is fastened to a steel frame, while the other end is raised and dropped by a cam motor driven through a system of gears and pulleys. The plunger, which is equipped with a rubber footing, can be adjusted for any desired height of fall.

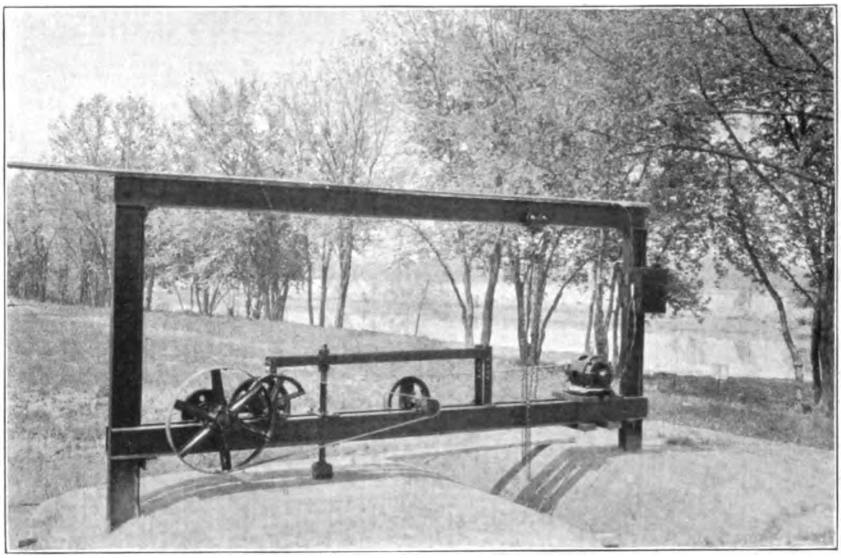


FIGURE 17.—SOIL VIBRATOR

The intensity of the plunger blow is determined by an accelerometer. Both slab and subgrade are caused to vibrate by the dropping of the plunger.

Used to determine the increase in capillary moisture in the subgrade, due to vibration of the slab and subgrade, in subgrade investigations, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING SUBGRADE TEMPERATURES

The apparatus for determining subgrade temperature, shown diagrammatically in Figure 18, consists of (1) thermo couples, (2) mercury contact panel, (3) constant temperature unit, and (4) potentiometer. The thermo couples consist of two wires, copper and constantan (60% Cn.—40% Ni.) soldered together and inserted in glass tubes, which are sealed with paraffin throughout their entire length to prevent leakage of electricity or water. The leads from the tubes are enclosed in rubber tubing of sufficient length to reach above the surface. The tubes are sealed with sealing wax. The mercury contact panel consists of a number of small cups, so arranged that electrical contact with them can be made. The cups are filled with mercury. The constant temperature unit consists of a commercial vacuum flask, in which is inserted a glass tube containing about 1 inch of mercury. The copper wire of each thermo couple is connected to one of the small cups in the contact panel. The constantan wires of the thermo couple are connected to the constantan lead, whose one end is inserted in the mercury in the constant temperature unit. A copper wire inserted in the same mercury is connected to one of the leads of the potentiometer. To the other lead of the potentiometer is connected a copper wire having a bare point. The difference in temperature between the constant temperature unit and the thermo couples is indicated by the resistance required to sustain constant potential in the system. Observation for temperature of any thermo couple is made by inserting the bare end of the copper wire attached to the potentiometer into the mercury cup, to which is attached a copper wire leading to the respective thermo couple, and reading the resistance necessary for maintaining constant potential. All wires exposed to the atmosphere are protected by a coating of shellac.

Used to determine temperatures in slabs and at various depths in the subgrade beneath, at the Arlington Experimental Farm, Arlington, Virginia.

Adapted to this use by the U. S. Bureau of Public Roads.

Illinois: Illinois Division of Highways.

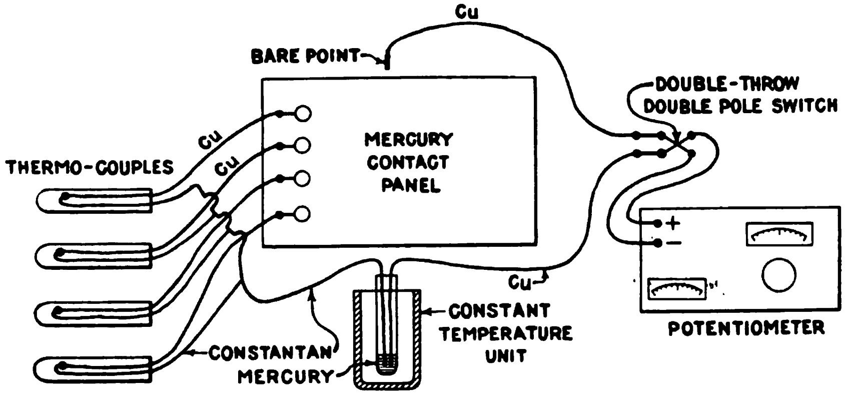


FIGURE 18.—APPARATUS FOR DETERMINING SUBGRADE TEMPERATURES

STATIC-LOAD BEARING POWER DETERMINATOR

The static-load bearing power determinator (Figure 19), consists of a three-legged, iron-pipe frame, carrying a Toledo Automatic Hanging Scale, from which is suspended a pail containing about 30 pounds of shot. The load is applied to the subgrade by means of a steel rod, terminating in a brass shoe. This rod supports a pan, which receives the shot from the pail. A thumbscrew in the frame enables the operator to control the rod movement, which is measured by an Ames dial. An initial reading is taken, with the shoe resting on the subgrade without any load, after which the shot is released and readings are taken for total loads of 10, 20, and 30 pounds. Additional readings are then taken for two minutes at intervals of

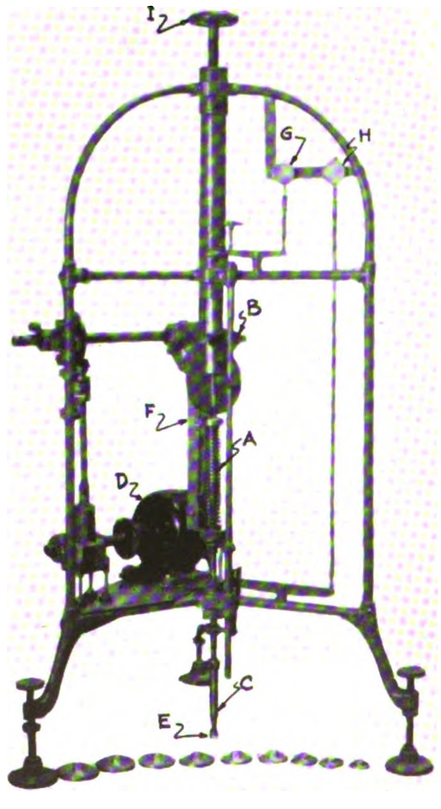


FIGURE 20.—ILLINOIS REPEATED-LOAD BEARING POWER DETERMINATOR

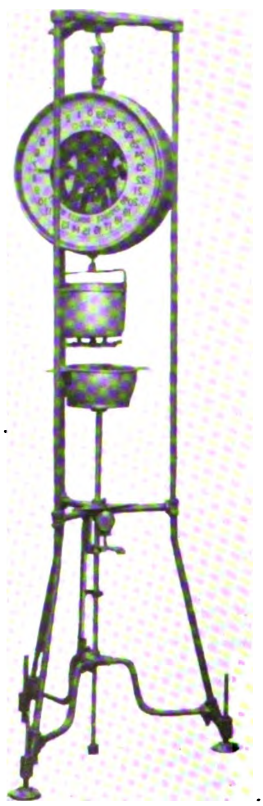


FIGURE 19.—ILLINOIS STATIC-LOAD BEARING POWER DETERMINATOR

thirty seconds under the 30-pound load. The load is then removed and the upward movement of the rod is measured.

Used in 1920 and 1921, during the construction of the Bates experimental road in the study of the relative supporting values of the subgrade under various sections of the road.

Designed by Clifford Older, Chief Highway Engineer, Illinois Division of Highways, and B. H. Piepmier, former Engineer of Construction, Illinois Division of Highways.

Described in "Preliminary Report on Bates Road Tests," by Clifford Older and H. F. Clemmer, Public Roads, Vol. 4, No. 5, September, 1921.

Constructed by Illinois Division of Highways.

ILLINOIS REPEATED-LOAD BEARING POWER DETERMINATOR

The repeated-load bearing power determinator (Figure 20), consists mainly of a pipe frame, in which is mounted a spring (A) for producing pressure; a cam (B), which varies this pressure; a plunger (C), which transmits the pressure to the soil; a one-sixth horsepower D. C. motor (D), which drives the cam at a constant speed of six revolutions per minute; a footing (E), which is attached to the bottom of the plunger and distributes the pressure to the soil (footings of different areas are shown at the bottom of the machine in the illustration); a scale (F) upon which the pressure desired is set; an Ames dial (H), which registers the action of the soil under repeated loads; a wheel (I) which lowers the cam action; and a second Ames dial (G), which registers the vertical movement of this section.

The object of this instrument is to subject the soil to such pressure as might be expected under a road slab during the passage of vehicles. By use of the cam the pressure is increased gradually from zero to maximum, and then decreased to zero. This is similar to the pressure exerted at any point in the subgrade as a moving vehicle passes over a rigid slab. The time of application of load with this apparatus is such as would be expected from a vehicle traveling over a 7-inch concrete surface at the rate of about 15 miles per hour. By changing the spring pressure, the magnitude of the load can be made similar to that which would occur under any thickness of slab. The effect of area of contact upon soil deformations caused by constant pressure intensity can be determined by use of shoes of different footings.

Used in 1921–22 on the Bates Experimental Road, and also in studies of subgrades in various parts of Illinois.

Designed by Clifford Older, Chief Highway Engineer, H. F. Clemmer, Engineer of Tests, and A. C. Benkleman, Assistant Engineer of Tests.

See "New Device for Testing Subgrade Bearing Power," by H. F. Clemmer, Engineering News-Record, September 15, 1921.

Constructed by Bureau of Tests, Illinois Division of Highways.

ILLINOIS SUBGRADE TESTING CYLINDER

The subgrade testing cylinder (Figure 21), consists of a 1¾ by 1½-inch black iron reducer (A), a short length of 1½-inch black iron pipe (B), a special 1¾-inch black iron plug (C), a special 1½-inch brass bearing plug (D), a short sleeve of 1¼-inch black iron pipe (E), and a 1¼ by 1½-inch brass disc (F). Plug (C) is flush with the surface of the concrete, and the disc (F) rests freely on

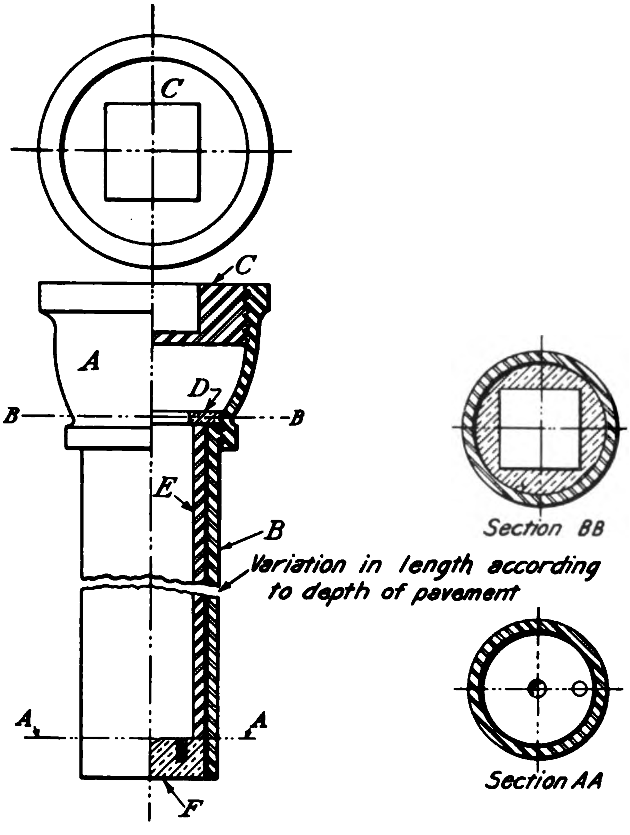


FIGURE 21.—ILLINOIS SUBGRADE TESTING CYLINDER

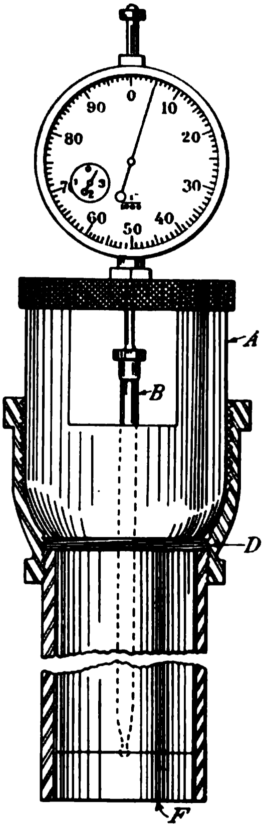


FIGURE 22.—APPARATUS FOR READING ILLINOIS SUBGRADE TESTING CYLINDERS

the subgrade. The length of the pipe (B) and the sleeve (E) varies with the depth of the pavement in which the tester is placed. An Ames dial arranged in a special apparatus (Figure 22), is used for reading these testers. The support (A) into which the Ames dial is screwed, sits snugly against the brass plug (D). The plunger of the Ames dial rests on the rod (B), which fits in a small circular depression in the center of the disc.

The subgrade tester can be used for various purposes. With the special reading apparatus, separation between the subgrade and surface can be measured. By using the disc (F) as a footing for the static load determinator, the supporting value of the subgrade can be determined. By removing the brass bearing plug (D), and the disc (F), access is had for securing soil samples for the determination of moisture content or study of other properties.

Used in 1921–22 on Bates Experimental Road.

Designed by Clifford Older, Chief Highway Engineer, Illinois Division of Highways, H. F. Clemmer, Engineer of Tests, Illinois Division of Highways, A. E. Stoddard, Assistant Engineer of Tests, Illinois Division of Highways.

Described in Engineering News-Record, June 30, 1921.

Constructed by Bureau of Tests, Illinois Division of Highways.

2. *Investigations of Road Surface, Structures and Appurtenances.*

District of Columbia: U. S. Bureau of Public Roads.

WEAR TESTING MACHINE

As shown in Figure 23, the wear-testing machine consists of five cast-iron wheels, 48 inches in diameter by 2 inches wide, and each weighing 1,000 pounds, thus giving a unit wheel load of 500 pounds per inch width of tire. The wheels are mounted inside a channel-iron frame in such a way that each wheel, independently of the others, is free to move up and down, and thus adjust itself to any inequalities or depressions in the pavement.

It was designed to approximate the effect of action produced by heavily-loaded, steel-tired trailers or horse-drawn vehicles.

Used to produce wear on pavement sections in U. S. Bureau of Public Roads Wear Test on Pavement Sections, Arlington Experimental Farm, Arlington, Virginia. The machine was pulled back and forth over the test sections by means of an endless steel cable driven by a 30-horsepower gasoline engine, and traveled at the rate of five miles per hour.

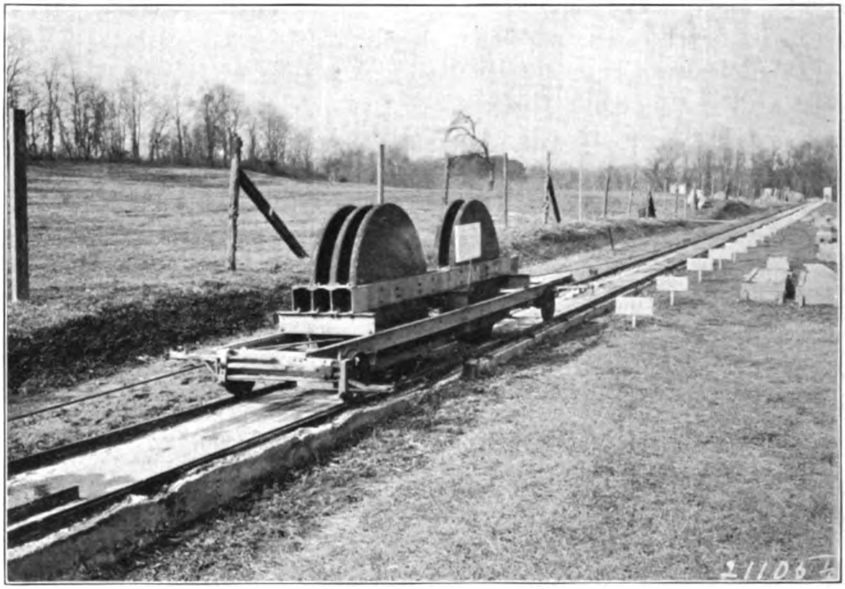


FIGURE 23.—WEAR TESTING MACHINE

Designed and constructed by the U. S. Bureau of Public Roads.

See "Report of Wear Tests on Pavement Sections," by F. H. Jackson and C. A. Hogentogler, Public Roads, Vol. 4, No. 2, June, 1921.

ABRASION APPARATUS

As shown in Figure 24, the abrasion machine consists of two wear-producing wheels, A and B, so arranged in a steel-frame, 4-wheel truck that the position of the wheels on the axles can be changed and the wheel loads can be varied. The wheel (B) through which the power is applied for propelling the apparatus, simulates the action of the rear wheel of a motor vehicle, while the wheel (A), which moves freely, corresponds to a front wheel. The apparatus is driven by an electric motor to which the power is supplied by means of a third rail and plow.

Used in investigations of wear of different types of concrete surfaces, Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Designed and constructed by the U. S. Bureau of Public Roads.

See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

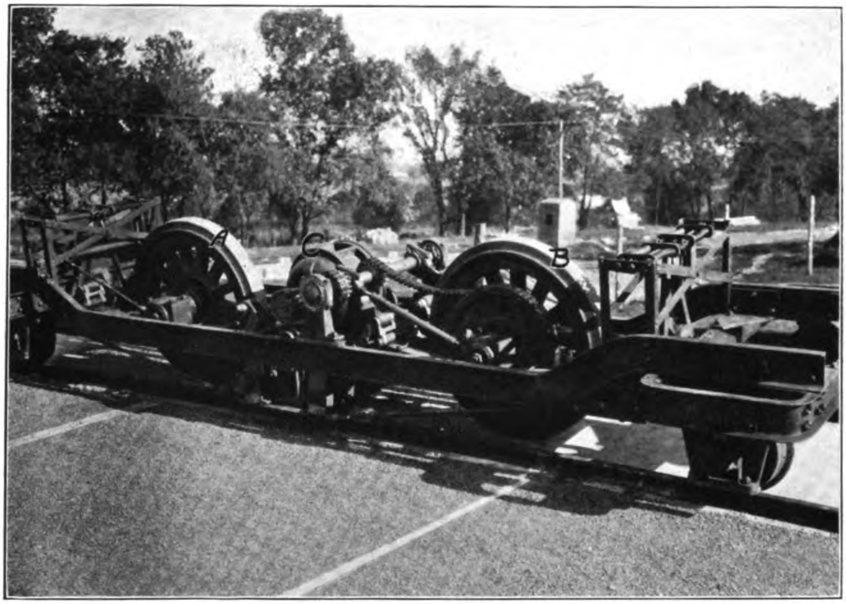


FIGURE 24.—ABRASION APPARATUS

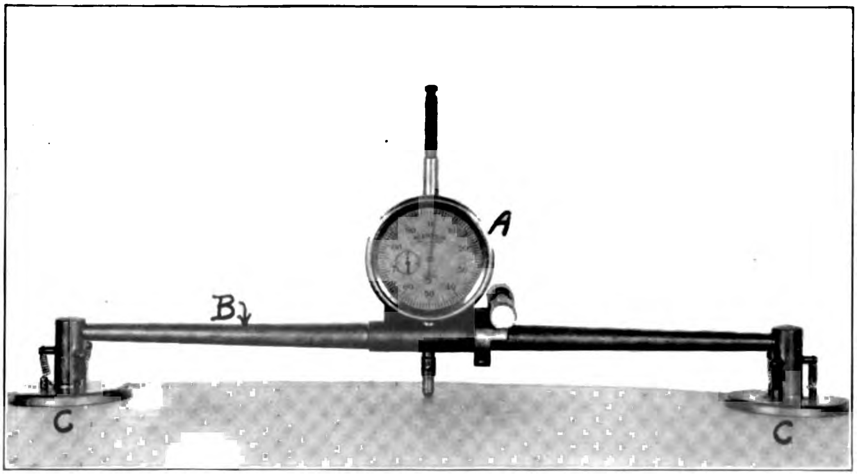


FIGURE 25.—WEAR MEASURING INSTRUMENT

WEAR MEASURING INSTRUMENT

The device, as shown in Figure 25, consists of an Ames dial (A) mounted on a brass beam (B) supported at each end by a swivel footing (C). The footings rest on the pavement surface and the dial plunger rests on a datum, which consists of a brass plug in a small brass cylinder set in the pavement surface. Between observations, the brass plug, which is about ½ inch below the top of the pavement, is protected by cotton waste and putty placed above it in the cylinder whose top edge is flush with the surface. The wear of the surface is indicated by the difference in dial readings in successive observations.

Used in investigation of wear of different types of concrete surfaces, Arlington Experimental Farm, Arlington, Virginia, and by the U. S. Bureau of Public Roads in co-operation with the Delaware State Highway Department, to determine surface wear of concrete roads.

Designed and constructed by the U. S. Bureau of Public Roads.

SLAB IMPACT MACHINE

This apparatus consists of a loaded box riding on a 5½-ton spring, which in turn is supported by a loaded frame or plunger on the bottom of which is a section of double 2 by 6 inches solid-rubber tire. The box and plunger, representing the sprung and unsprung weights, respectively, can be so loaded as to represent a truck of any size or load. By means of a motor, gears, and cam, the plunger or unsprung weight carrying the spring and sprung weight, can be lifted and dropped from any height so that the effect produced approximates that of a motor-truck wheel dropping from one level to another, dropping into a hole or falling to the pavement after striking an obstruction.

Used to test pavement sections in impact tests of the U. S. Bureau of Public Roads, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Impact Tests on Pavement Sections," by C. A. Hogentogler, Public Roads, Vols. 6 and 7, October and November, 1921.

PORTABLE IMPACT MACHINE

This machine consists, as shown in Figure 26, of a motor-truck wheel supported in a heavy frame which in turn is carried on a heavy, motor-truck spring. This constitutes the unsprung weight and is supported in a vertical motion by means of cams carried on the outside, supporting, angle-iron frame. The apparatus is electrically driven. The height of the drop of the truck wheel can be varied from 0 to 6 inches and the rate of application of load from 6 to 10 drops per minute. By varying the spring pressure and using suitable wheels and weights, a range of impacts from 0 to those which would be expected from the heaviest of motor trucks, can be obtained.

Used to test pavement sections by the U. S. Bureau of Public Roads, Arlington Experimental Farm, Arlington, Virginia.

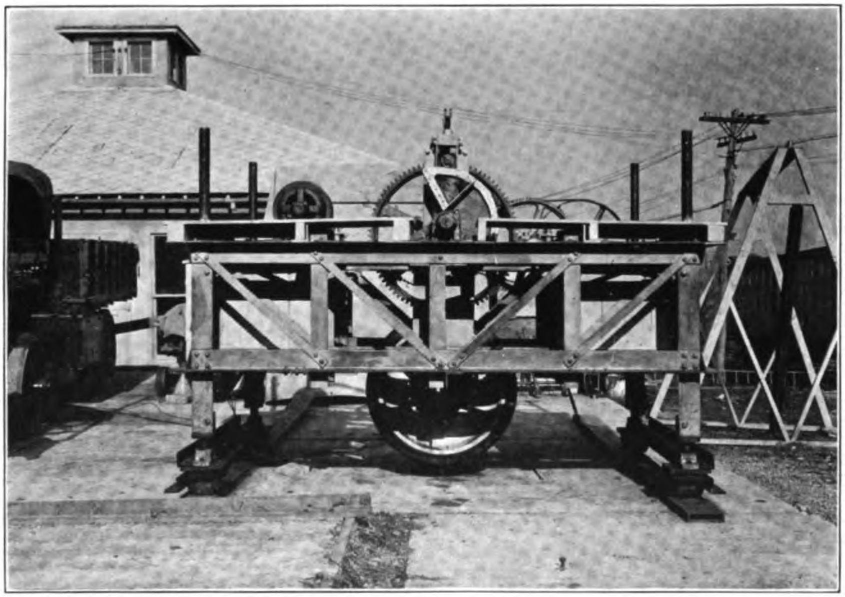


FIGURE 26.—PORTABLE IMPACT MACHINE

Designed and constructed by the U. S. Bureau of Public Roads. See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

SPACE-TIME RECORDER

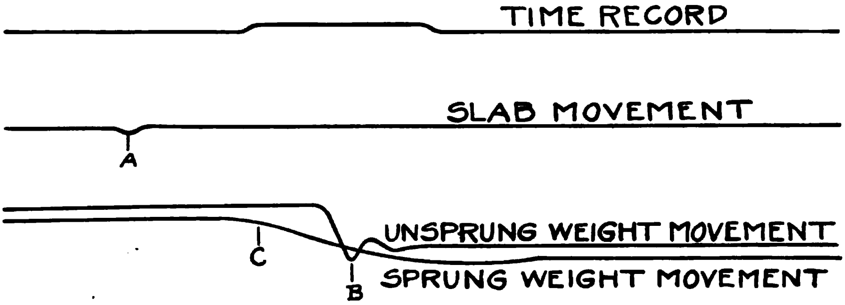
This apparatus, which was attached to the first impact machine, consists of a revolving drum 5 inches in diameter over which is drawn a band of siliconized paper. Three brass points resting against this paper and connected by means of a ¼-inch square steel rod to the respective parts, record the vertical movements of the sprung and unsprung weights as well as the deflections of the test slabs under impacts. A fourth brass point actuated by an electric magnet, records the time in seconds. An enlarged record secured from one drop of the plunger of the impact machine is shown in Figure 27. The slab deflection as shown at A occurs when the unsprung weight has reached its lowest position at B, while the position of the sprung weight at the same time is shown at C.

An improved form of the space-time recorder was attached to the second impact machine. Besides having modifications in the mechanical details, this apparatus was electrically driven, and the time was recorded every .03 of a second.

Used to measure impacts delivered by the impact machine, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

For complete details of apparatus and methods of computing impact force from space-time curves, see "Impact on Pavement Section," by C. A. Hogentogler, Public Roads, Vol. 4, No. 6, October, 1921, and "Measurement of Impact," by E. B. Smith, Proceedings of the A. S. T. M., 1921.



AUTOGRAPHIC RECORD OF $\frac{7}{8}$ INCH DROP OF PLUNGER OF IMPACT MACHINE.

FIGURE 27

ACCELEROMETER FOR MEASURING IMPACT FORCES

This device, shown in Figure 28, consists of a metal frame supporting a flat steel spring (A) attached to which is a small weight or plunger (B). Any vertical acceleration to which the instrument is subjected is accompanied by a corresponding deflection of the spring. This deflection is measured in the following manner: The bottom of the plunger (B) is triangular in shape and rests in a triangular space in the frame of the apparatus. The sides of the triangular base and the triangular space are not parallel, and are separated by two steel rollers (C). As the plunger moves downward during the sprung deflection, the rollers held by small spiral springs follow the movement and prevent the plunger from returning to its

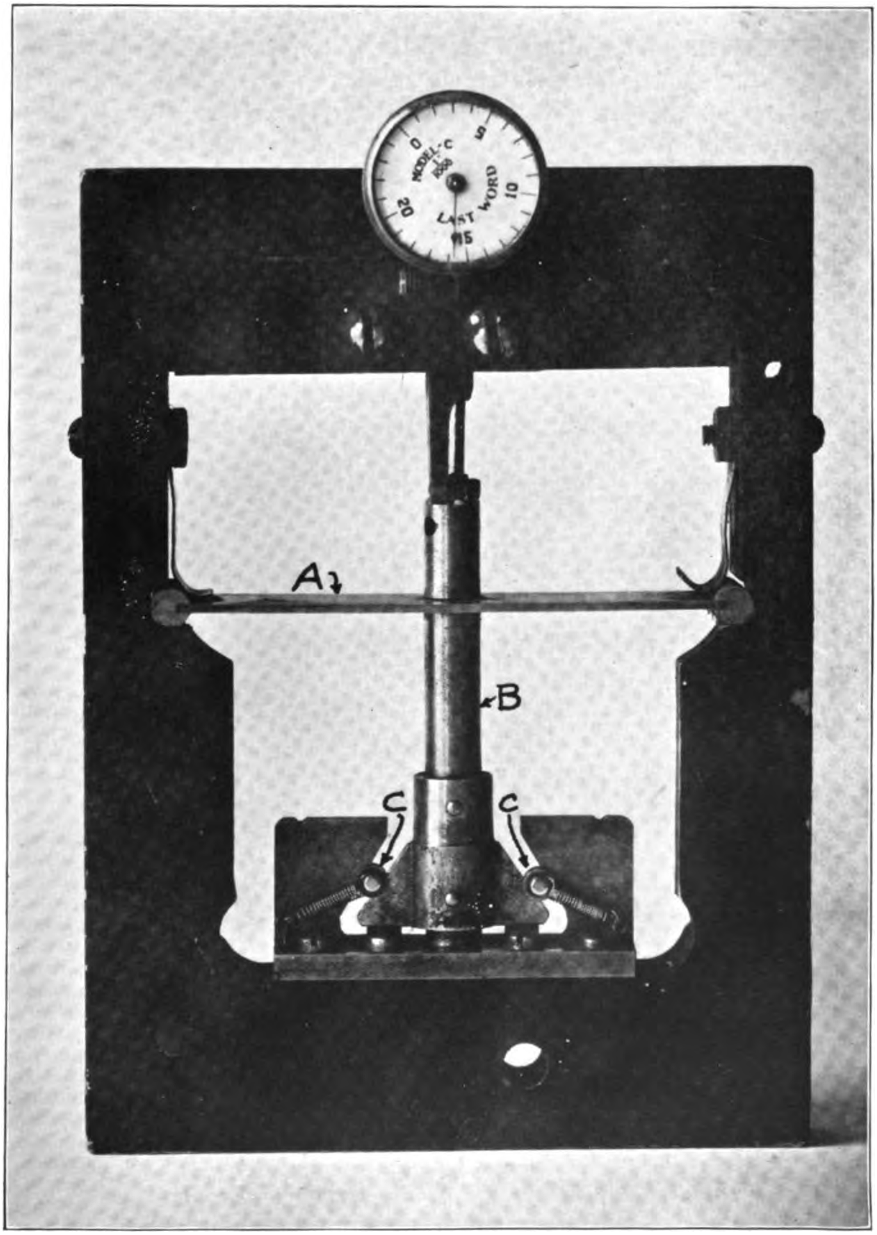


FIGURE 28.—ACCELEROMETER

original position. A Last Word dial is attached to the top of the frame with its stem resting on top of the plunger; thus the difference in elevation of the plunger before and after an impact occurs, is measured by the dial and represents the spring deflection. After properly calibrating the instrument, accelerations can be easily computed from the dial readings.

The instrument has been used to measure impacts delivered by the portable impact machine (see B, Figure 33) at the Arlington Experimental Farm, Arlington, Virginia. If it is attached to a truck running over a road, it will record the maximum acceleration which occurred during the operation.

Designed and constructed by the U. S. Bureau of Public Roads.

MIRROR ACCELEROMETER FOR MEASURING IMPACT FORCES

This device, shown in Figure 29, is a modification of the one described above. The spring (A) and the small weight (B) are similar to those used in the first instrument, but for measuring the deflection a ray of light is used instead of the dial. A light ray from the lamp (E) passing through a lens (F) and striking a mirror pivoted at D, is reflected on the ground glass (G) shown at the top of the frame. Any movement of the plunger (B) causes a slight rotation of the mirror and changes the position of the ray of light reflected on the ground glass. A small brake (C), resting against the mirror, holds the mirror in its position of maximum rotation until the measurement of the movement of the light ray on the ground glass can be secured. To facilitate this measurement, the ground glass has a scale cut on it. After the proper calibration, the acceleration can easily be determined from the distance which the light ray moves on the ground glass.

Used at the Arlington Experimental Farm, Arlington, Virginia, and in studies of the effect of roughness of different types of road surfaces.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR MEASURING IMPACT BY USE OF SMALL COPPER CYLINDERS

This apparatus consists of a jack set in a concrete foundation in such a manner that the top of the jack is flush with the surrounding surface, as shown in Figure 30. Small copper cylinders, ½ inch in diameter by ½ inch high, having previously received special heat treatment to insure uniformity, are deformed in the jack by blows received on its top from moving motor-truck wheels. The force of the impact blow in each case is considered as equivalent to the weight in pounds which, applied statically, would cause the same deformation. By using different heights of drop and wedges and blocks on top of the jack, the effects of holes in the road surface, as well as of

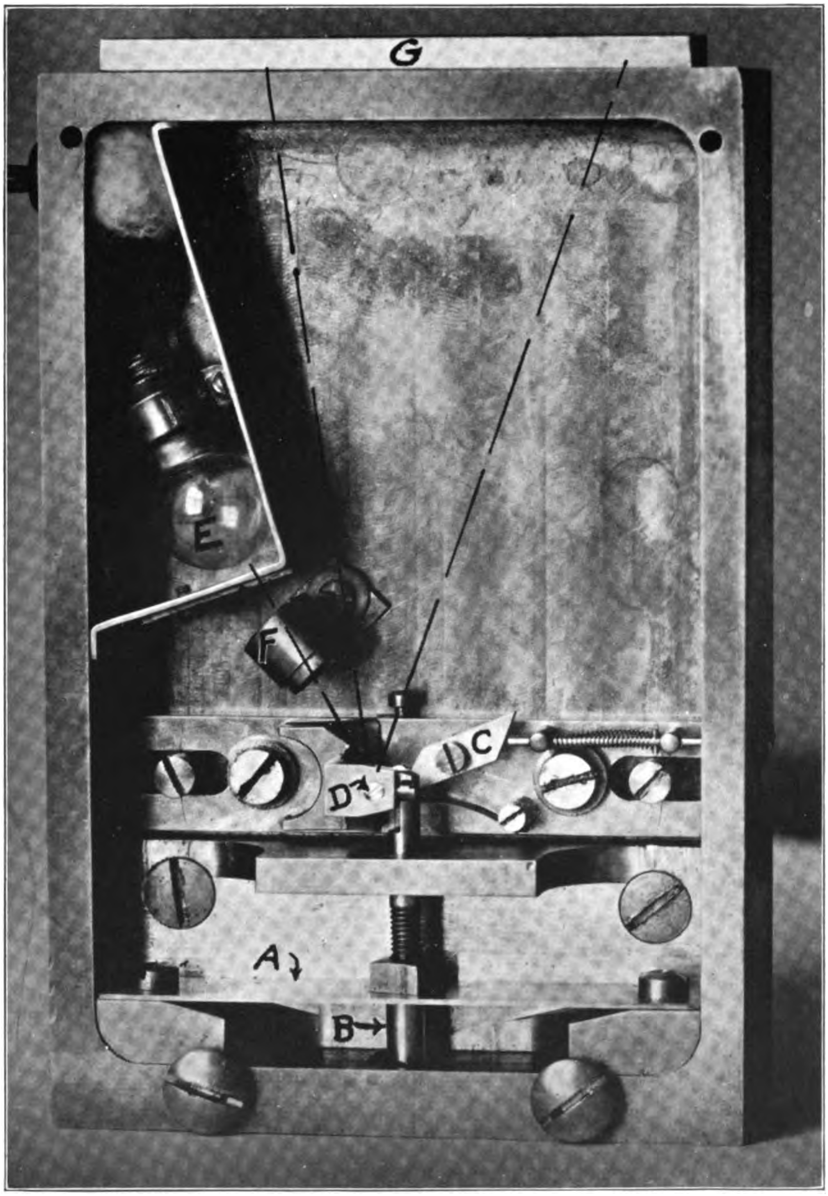


FIGURE 29.—MIRROR ACCELEROMETER

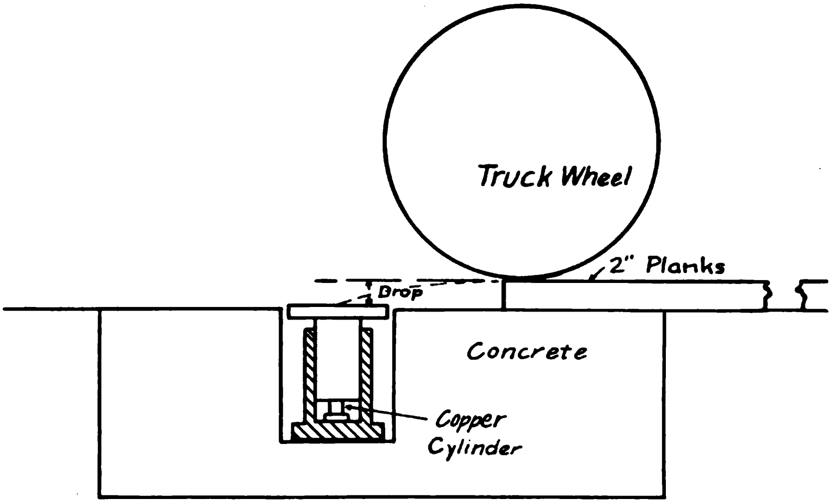


FIGURE 30.—APPARATUS FOR MEASURING IMPACTS BY USE OF SMALL COPPER CYLINDERS

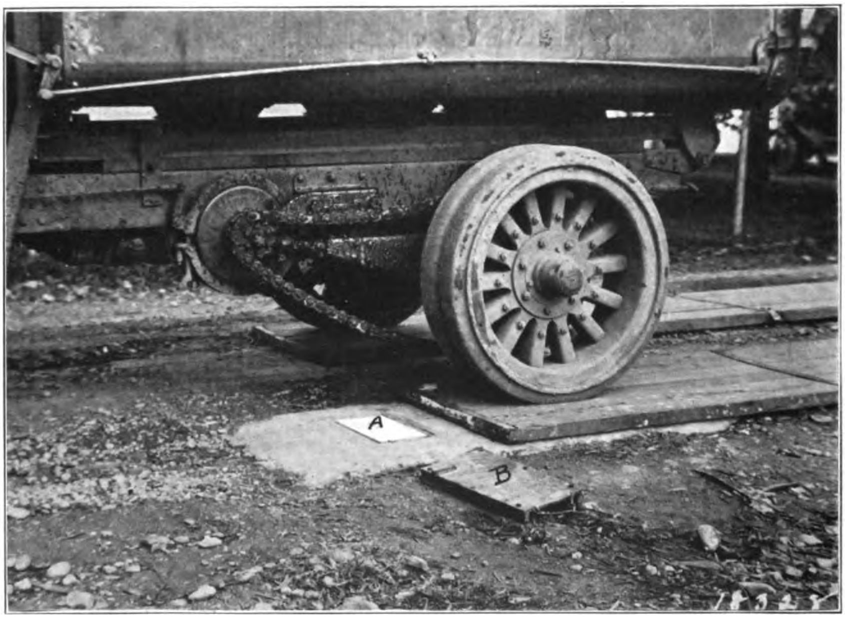


FIGURE 31.—MEASURING IMPACT OF REAR MOTOR TRUCK WHEELS

obstructions, have been simulated. Figure 31 shows the top of the jack (A) about to receive the blow from the truck wheel. The small piece of channel iron (B), with wire attached, spans the top of the jack during the passage of the front wheel, and is withdrawn to allow the blow of the rear wheel to be measured.

Used at Arlington Experimental Farm in impact tests of motor-truck wheels.

Adapted by the U. S. Bureau of Public Roads from method employed by the U. S. Army to determine force of explosives in guns.

See "Motor Truck Impact Tests of the Bureau of Public Roads," by E. B. Smith, Public Roads, Vol. 3, No. 35, Vol. 4, No. 8, March and December, 1921.

ADAPTATION OF KREUGER METHOD FOR MEASURING IMPACT

The apparatus consists of a jack, Figure 32, containing a chrome-nickel block with a flat surface against which rests a chrome-nickel block with a spherical surface. The area of contact between the two surfaces is dependent upon the force exerted upon the top of the jack. By calibration in a testing machine the load causing different

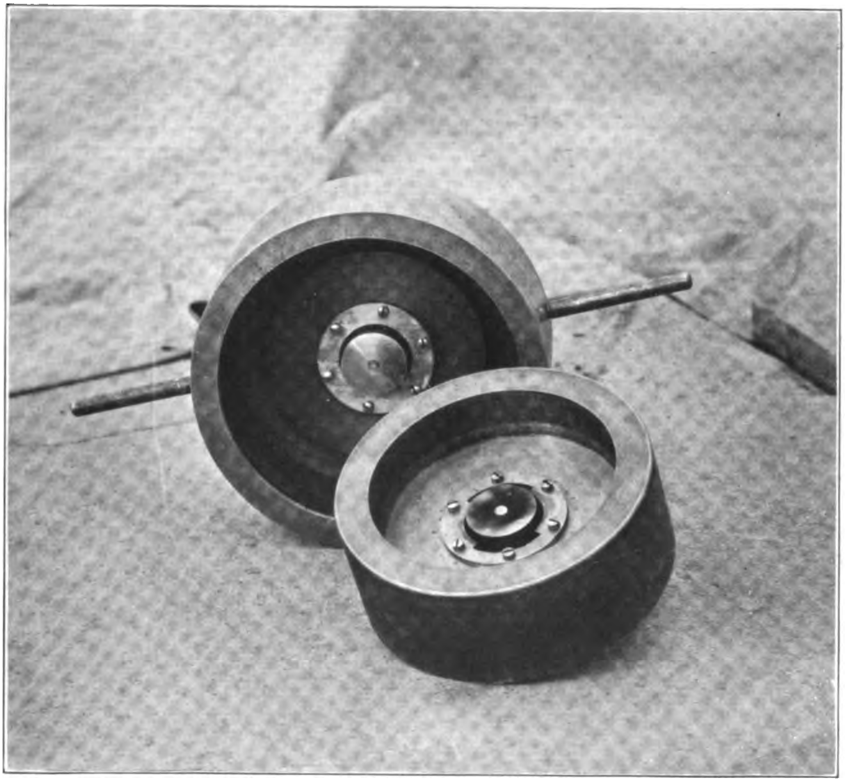


FIGURE 32.—ADAPTATION OF KREUGER METHOD FOR MEASURING IMPACT

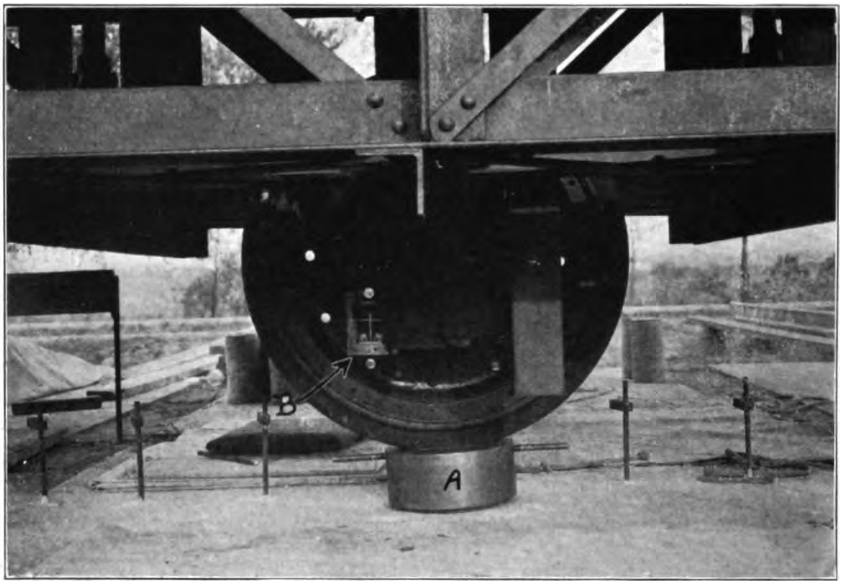


FIGURE 33.—MEASURING IMPACTS BY THE KREUGER METHOD

areas of contact is obtained and a curve showing the relation of load to contact is drawn. For the purpose of obtaining a record of the area of contact between the two blocks, the face of the one having the flat surface is smoked so that after the contact the area is plainly marked on the highly polished steel. From the calibration curve the force which caused a given area is easily ascertained. Figure 33 shows the jack (A) receiving a blow from the impact machine, while Figure 32 shows the impression made on the flat surface by its contact with the spherical block. The size of the blocks is such that no permanent deformation occurs under the forces to which they are subjected.

Used to determine the force of impacts delivered in the second series of impact tests at Arlington Experimental Farm, Arlington, Virginia.

See "Methods for Measuring and Calculating the Magnitude of Forces with Particular Regard to Impact Forces," by Professor Kreuger in Translations No. 2, Engineering and Science Academy, Stockholm, 1921.

INDICATOR FOR MEASURING VERTICAL MOVEMENT OF ROAD SLABS

The device (Figure 34) for measuring vertical movement of pavement edges, due to either warping or load, consists of a pointer ar-

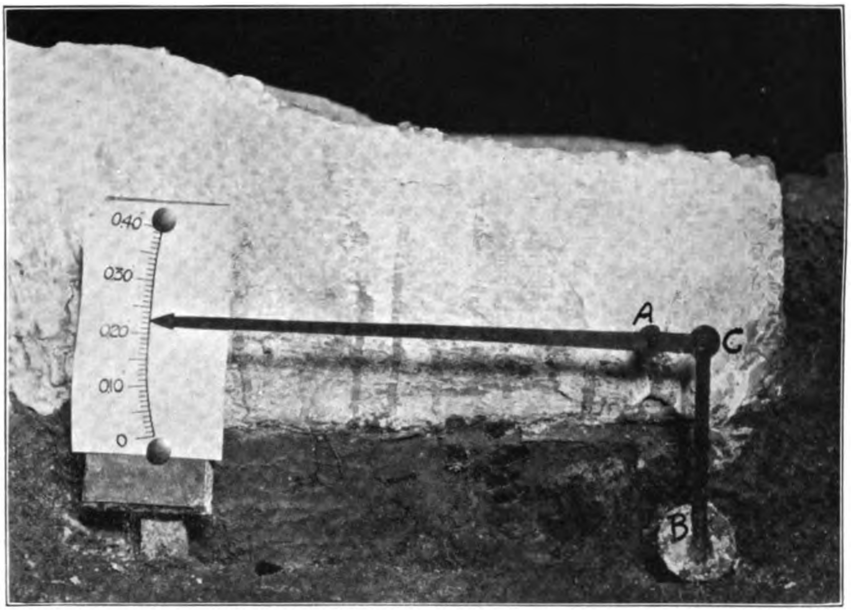


FIGURE 34.—INDICATOR FOR MEASURING VERTICAL MOVEMENT OF ROAD SLABS

ranged as a lever with one center (A) in the concrete and the other (B) in the subgrade. The movement at the free end of the pointer is ten times that of the end which receives the movement of the slab. The scale is increased by 10 so that the movement, as indicated on the scale, is the same as received by C or the actual movement of the slab with respect to the subgrade.

Used in making observations of warping of 18 by 30 feet concrete road slab at Arlington Experimental Farm, Arlington, Virginia.

Modification of the card scheme[2] used by the Illinois Division of Highways on the Bates Experimental Road.

Constructed by the U. S. Bureau of Public Roads.

ADAPTATION OF STRAINAGRAPH FOR RECORDING DEFLECTIONS OF ROAD SLABS

The strainagraph, set up as shown in Figure 35, records the vertical movement of road slabs due to warping. The movement of the corner of the slab is transmitted to the mechanism of the instrument by means of a rod (A) which is shown resting on the corner. The recording mechanism is driven by an electric motor so geared that an 8-day continuous record is secured on 50 feet of record paper.

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[2] "Paving Slab and Subgrade Studies in Illinois," by Clifford Older, Engineering News-Record, January 12, 1922, page 81.

Used at Arlington Experimental Farm, Arlington, Virginia, in the study of warping of road slabs.

Adapted by the U. S. Bureau of Public Roads.

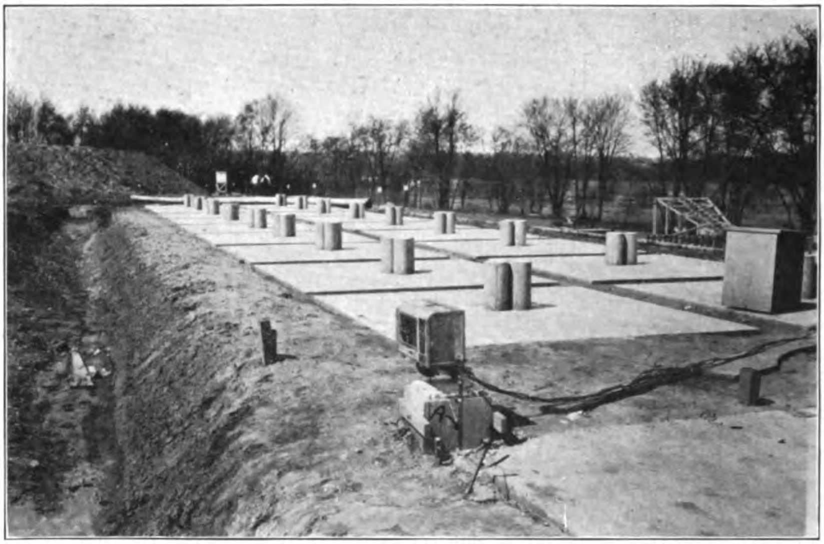


FIGURE 35.—RECORDING DEFLECTION OF ROAD SLAB WITH STRAINAGRAPH

APPARATUS FOR RECORDING AUTOGRAPHICALLY THE VERTICAL MOVEMENT OF PAVEMENT SLABS CAUSED BY WARPING OR LOADING

The apparatus, shown in Figure 36, consists of a motor-driven mechanism which draws a band of paper over a smooth board fastened to supports driven into the ground. The face of the board is parallel to the side face of the pavement surface. The highly-magnified, vertical movements of 20 points, 1 foot apart, on the side of the pavement surface, are recorded on the moving paper by as many pen points which are actuated by levers connecting them with the pavement. From these curves the shape of the side edge, and consequently an indication of stress existing therein, can be secured for any time and for any position of a motor-truck wheel. Used in the study of deflections of road slabs on the Columbia Pike Experimental Road, Arlington County, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

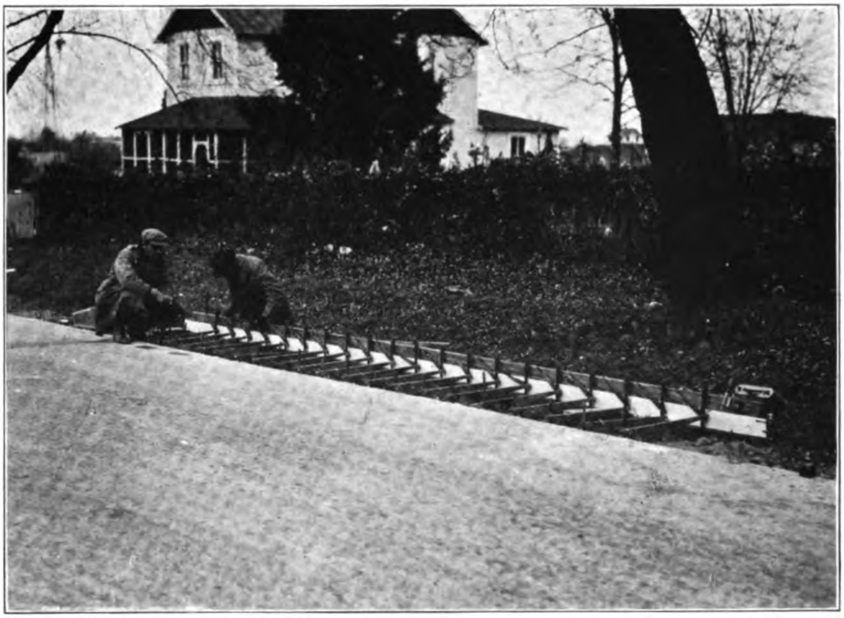


FIGURE 36.—APPARATUS FOR RECORDING AUTOGRAPHICALLY THE VERTICAL MOVEMENT OF PAVEMENT SLABS

STRAIN GAGE FOR DETERMINING MAXIMUM FIBRE DEFORMATION

This instrument is a modification of a similar device used by the Ohio State University. It consists of a distance bar to one end of which is attached a contact point; the other end rests against a small steel block in a steel cylinder. Spring pressure applied through a small plug causes sufficient friction to prevent free movement of the small steel block. In making an observation with this device, the gage points are set on the specimen, and the initial reading of the position of the block with respect to the end of the cylinder is made by means of the Ames dial, after which the load is applied. Any shortening of the distance between gage points is shown by an equal movement of the block. The final reading is taken with the Ames dial, the difference between the two readings indicating the fiber compression. To prevent movement of the block due to pressure of the dial stem during readings, it is held fixed in place by means of a set screw.

Used in the study of impact on highway bridges, co-operative research project carried on by the Iowa State Highway Commission, Iowa Experiment Station, and U. S. Bureau of Public Roads.

See Bulletin No. 63, Iowa State College of Agriculture and Mechanic Arts, "Preliminary Impact Studies, Skunk River Bridge on Lincoln Highway Near Ames, Iowa," by Almon H. Fuller.

TEN-FOOT MICROMETER STRAIN GAGE

This instrument consists essentially of two measuring tubes, one steel, one brass, supported so they cannot bend, and provided with rounded tips against which measurements are made with micrometer screws. By means of micrometer measurements, corrected to constant temperature, changes of length between plugs set in the concrete road are obtained.

The measuring tubes are supported at frequent intervals by brass discs fastened within a brass casing 2 inches in diameter. This casing extends the full length of the instrument and is surrounded and supported at intervals by another casing 3 inches in diameter. At the ends of this outer casing are two collars which rest in the supporting blocks. These blocks are provided with pins whose conical ends fit into holes drilled in bronze plugs set in the road during its construction. One end-supporting block is provided with flat-ended contact pins and the block at the other end of the instrument carries micrometer screws. Adjusting screws are provided merely to support the instrument on the road when not in use. Fiber collars are provided merely for protection when the tube is detached from the end-supporting block.

Knowing the coefficients of expansion of these tubes, obtained by calibration, the difference in the micrometer readings furnishes a mean of obtaining the temperature of the bars. This temperature can then be used in correcting the micrometer measurements to a standard temperature. Thermometers are inserted in the 2-inch casing at the ends of the instrument. The mean of these end temperature readings, as a rule, approaches within 1° C. of the temperature obtained from the micrometer readings.

Used in studies of expansion and contraction of concrete.

Designed and constructed by the U. S. Bureau of Public Roads.

For detail of its use, see U. S. Department of Agriculture Bulletin No. 532, "Expansion and Contraction of Concrete and Concrete Roads," by A. T. Goldbeck and F. H. Jackson, Jr., October 13, 1917.

GRAPHIC STRAIN GAGE

As shown in the diagrammatic sketch, Figure 37, and photograph, Figure 38, the graphic strain gage consists essentially of a short piece of brass (A) and a longer piece (B) connected by a piece of spring steel (H) which acts as a hinge around which the two pieces of brass rotate as permitted by the small space between them. Since the steel-spring connection (H) is set off the center line of the two pieces of brass, any pressure exerted on the ends of the brass piece will cause this rotation. Any change in overall length between the two contact points, K and L, set on the center line, causes rotation of the parts, this rotation being proportional to the change in length. The lever (C) attached to the small piece of brass (A) permits magnification of the movement of rotation or change of length between contacts. A record of the movement is accomplished by a point D in the free end of the lever moving over the surface of a small piece of glass (E) which has been previously smoked, and which is held fixed on the point D. The devices are so small that they can be inserted, as shown in F, into pavement surfaces in slots ¾ by ¾ by 6 inches in size.

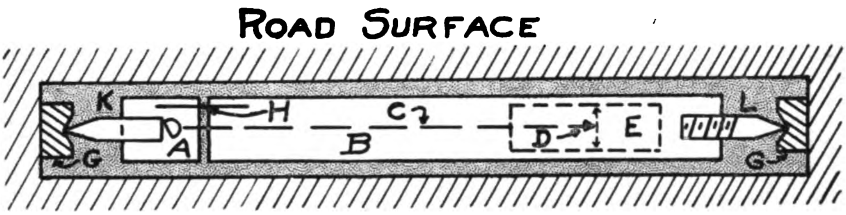


FIGURE 37.—DIAGRAMMATIC SKETCH OF GRAPHIC STRAIN GAGE

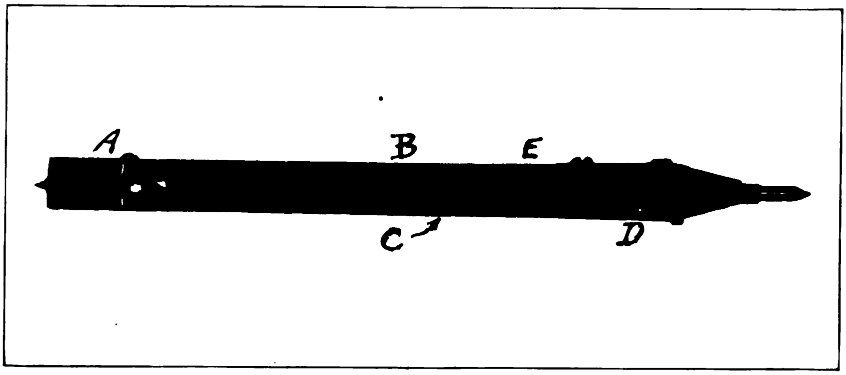


FIGURE 38.—GRAPHIC STRAIN GAGE

To make an observation, a slot of given dimension is cut in the surface of the road, small brass bearing plugs (G) are then set in plaster of Paris in the ends of the slot cut in the road surface, after which the strain gage is placed in position and adjusted to proper length by turning the contact point (L) until the indicator point is brought to the center of the small smoked glass E. After this position of D is attained, the piece of glass is moved a short distance so that a datum line is made on the record. A load is now applied and the record of both tension and compression occurring in the fiber is noted. Any compression shortens the overall length and causes D to move upward from the datum line, and any tension is shown below the datum line. A number of records can be secured in one piece of glass by simply moving it a slight distance after each load application.

After an observation has been made, the smoked glass record is removed from the strain gage and coated with a film of varnish, filed away, and later, by means of a microscope, is used for determining the fiber deformation.

Motor wheels can pass directly over these instruments which are protected by a thin cover plate. A number of them properly calibrated in various positions in the road slab, allows the determination of the direction, magnitude, and character of stress occurring with any type of moving or static load.

Used in the study of deformation and stress in road slabs on the Columbia Pike Experimental Road, Alexandria County, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See paper by A. T. Goldbeck, "What the Arlington Experiments Have Shown," presented before the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

PHOTOGRAPHIC STRAIN GAGE (FOR MEASURING IMPACT STRESSES IN BRIDGES AND OTHER STRUCTURES)

The optical principle and essential features of this strain gage are shown diagrammatically in Figure 39. A and B are the two gage points of the instrument, A being the movable gage point, pivoted as shown and operating a mirror at its upper end. A light is focused by means of a small lens on the mirror and is reflected back to the scale S. In operation any slight movement of the gage point A will rock the small mirror about its pivot, thus deflecting the beam of light along the scale, magnifying very greatly the maximum movement at A. By this means of magnification it will be seen that there are only two mechanical moving parts, namely, the gage point with its extension and the mirror on its pivot, and since the movement in either case is extremely small, they respond readily with very little inertia. The greater part of the magnification is attained by the reflection of the beam of light by the various mirror positions, and

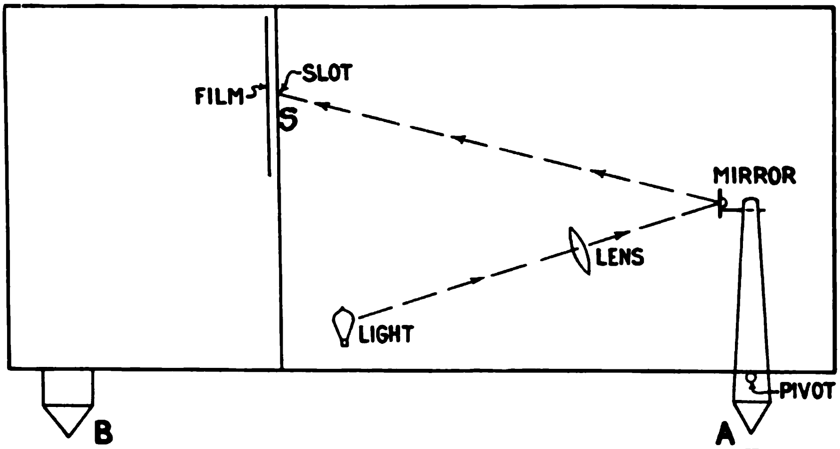


FIGURE 39.—SKETCH SHOWING PRINCIPLE OF THE PHOTOGRAPHIC STRAIN GAGE

this takes place with no inertia, consequently there can be no lag or over-travel. To make the instrument recording, a photographic film is so placed as to receive the record of the beam of light focused on a slot near the scale S.

A photograph of the actual instrument is shown in Figure 40, L being a small electric light bulb the filament of which is focused

FIGURE 40.—PHOTOGRAPHIC STRAIN GAGE

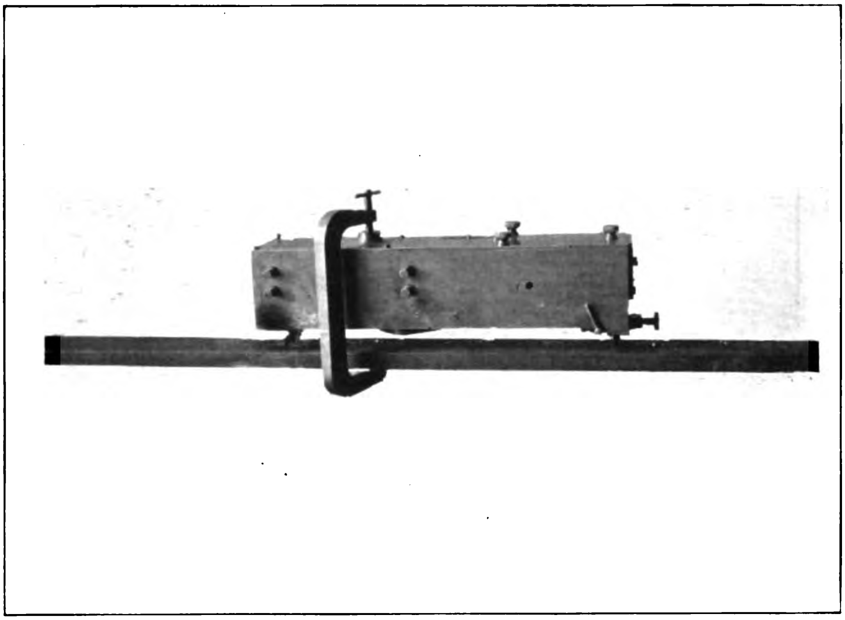


FIGURE 41.—PHOTOGRAPHIC STRAIN GAGE ATTACHED TO BRIDGE MEMBER DURING TEST

through the lens on to the small mirror at N. The image of this filament is reflected back across the vertical slot located in the partition of the instrument at T. A roll of film is caused to pass this slot and receive the record. In the closed end of the box is a small electric motor whose speed is reduced through a worm gear and which serves as the driving power for the film. The motor and the electric lamp are operated from a 12-volt storage battery. Figure 41 shows the instrument attached to a member in test. At the right end is the movable gage point which has a sliding longitudinal adjustment by means of the right hand thumb screw shown. At the left end are three gage points, the two outside gage points being of the same length and about 1/16 inch longer than the middle gage point. For use on flat surfaces, this provides a more stable and secure attachment for the instrument, but in case of narrow plates and bars and round rods, the center gage point is used.

Used in investigations of impact on highway bridges, Engineering Experiment Station, Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Preliminary Report on Impact Studies on the Skunk River Bridge, on the Lincoln Highway, Near Ames, Iowa," by Almon H. Fuller, Proceedings A. S. C. E., March, 1923.

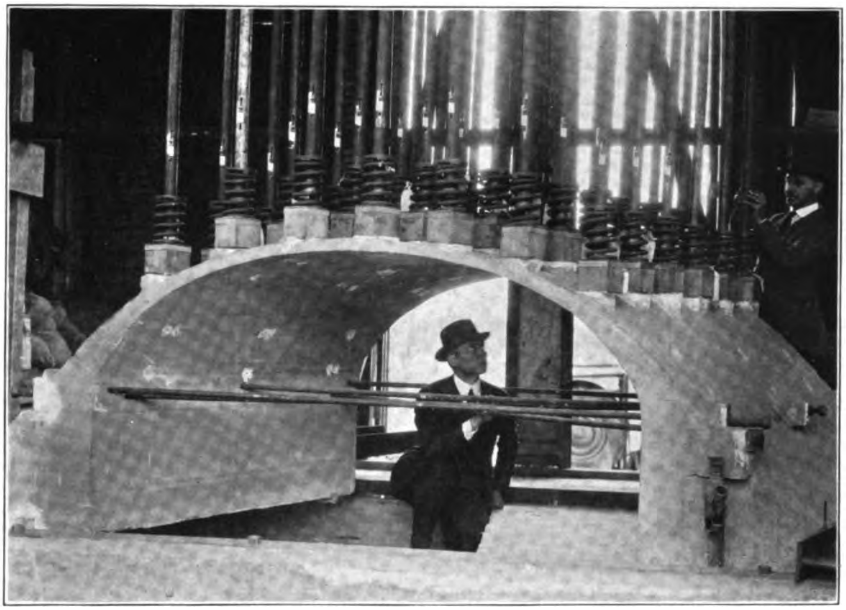


FIGURE 42.—TEST OF SKEW ARCH

APPARATUS FOR TESTING SMALL-SIZE SKEW ARCHES

As shown in Figure 42, the loads are applied to the test specimens by means of a number of springs placed at different points. The compression of each spring can be varied by turning an adjusting nut on top of the spring bearing rod. The applied load is determined by measurement of the deformation of the previously calibrated springs.

The deformation of fibers of the arch is measured by strain gages and the thrusts on the abutments are determined by use of special adaptations of the Kreuger measuring device.

Used in test of small skew arches, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR TESTING BEAMS IN THE FIELD

As shown by diagram and photograph, Figures 43 and 44, the apparatus consists of a steel I-beam grillage carrying angle-iron knife edges spaced 6 feet apart on which the beam is placed. A load is applied through a wooden beam 6 inches square and 13 feet long. This is removable to facilitate the placing of the specimen. In test-

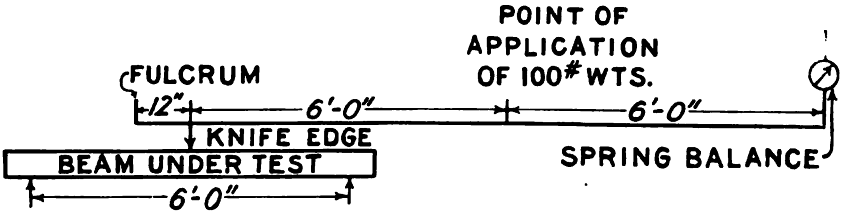


FIGURE 43.—SKETCH SHOWING PRINCIPLE OF BEAM TESTING APPARATUS

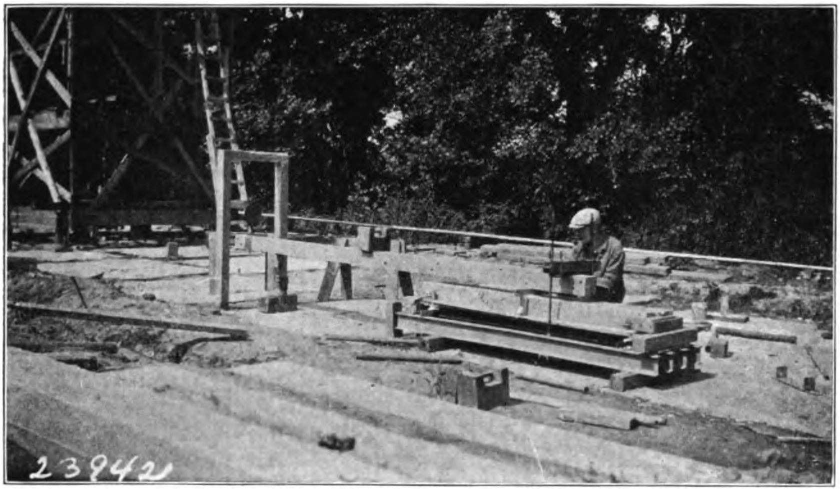


FIGURE 44.—BEAM TESTING APPARATUS

ing the specimen the beam is placed in position, one end supported by the angle iron resting on the specimen, and the other end hung on a spring balance held up by a turnbuckle on a ½-inch diameter steel rod fixed at the top. Proper contact is then made at the fulcrum and the load is applied by lowering the end of the beam at the spring balance by means of the turnbuckle. The load is computed by the reduction in the support of the free end of the beam as indicated by the spring balance. When the weight of the beam is insufficient to break the specimen, one-hundred-pound weights are placed in the middle of the beam.

Deflection of the specimen under test is measured by Ames dials independently mounted on each side of the apparatus bearing against supports attached along the neutral axis of the specimen.

Used in impact tests at Arlington, first series, to test beams 13 inches wide by 7 feet long, representing various types of pavements.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Impact Tests on Pavement Sections," by C. A. Hogentogler, Public Roads, Vol. 4, Nos. 6 and 7, October and November, 1921.

Illinois: Illinois Division of Highways, Springfield, Illinois.

STRAIN GAGE FOR MEASURING FIBRE DEFORMATION IN CONCRETE SLABS SUBJECTED TO STATIC LOADS

This instrument (Figure 45) is sensitive to the one hundred-thousandth of an inch with the use of a ten-thousandth-inch Ames dial. The true surface fiber elongation causes an exaggerated move-

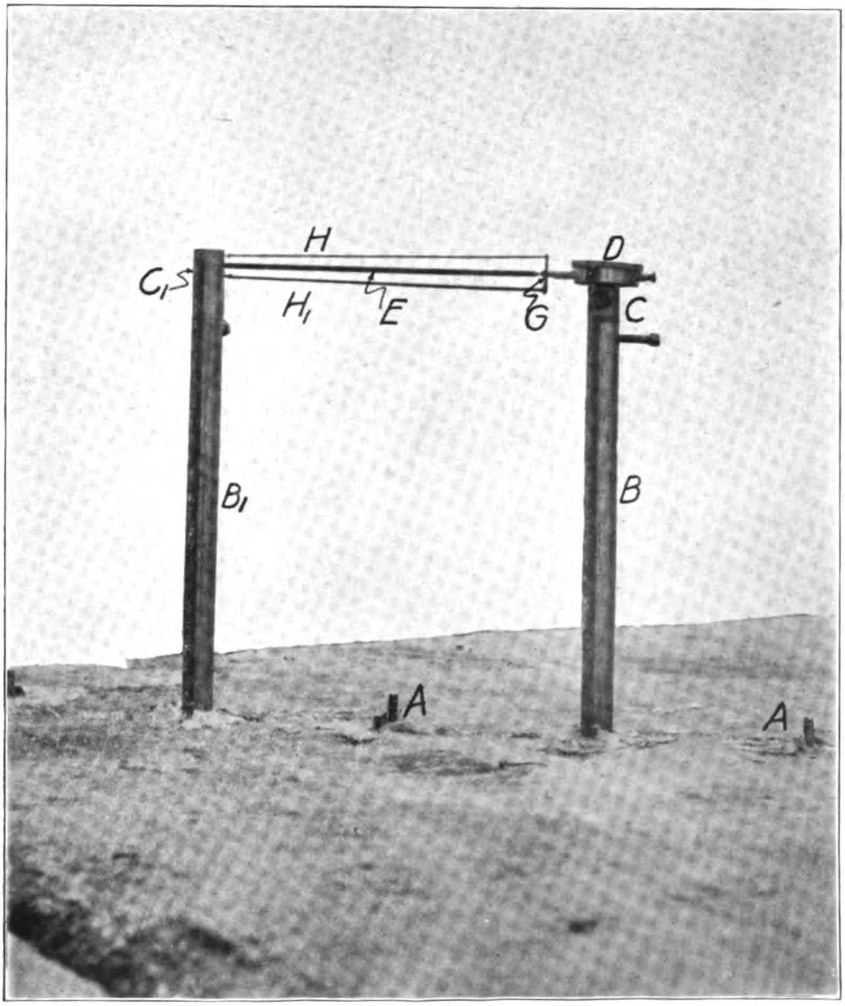


FIGURE 45.—ILLINOIS STRAIN GAGE

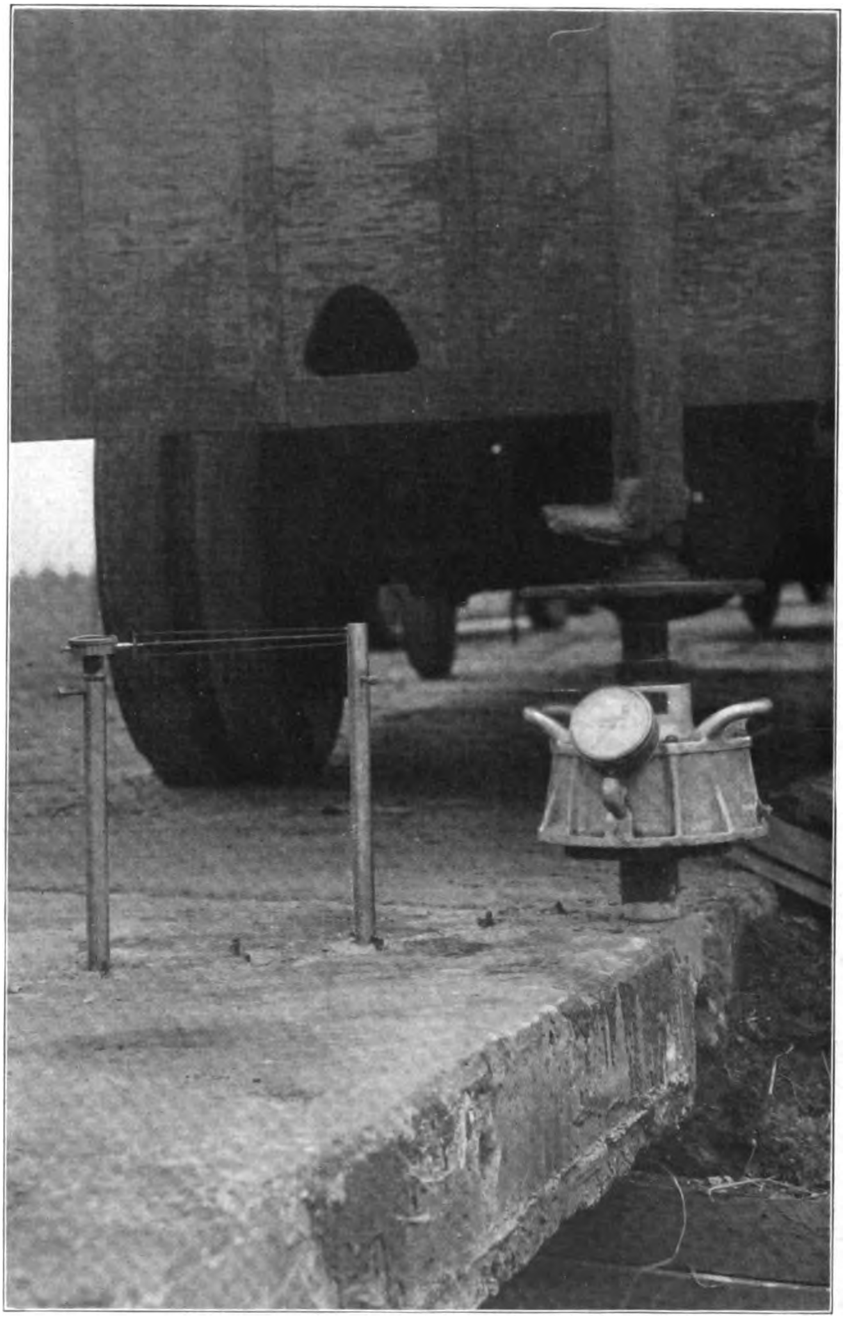


FIGURE 46.—MEASURING FIBER DEFORMATION WITH ILLINOIS STRAIN GAGE

ment dependent upon the length of the extension posts. A shows plugs set in the slab. B and B_1 are extension posts which screw on plugs. C is an adjustable head which holds dial (D). C_1 is also an adjustable head drilled out to receive pointed rod (E). The dial stem head is drilled to receive the other end of rod (E). By means of arm (G) fastened to dial stem and two rubber bands (H and H_1), the dial stem has positive action according to the movement between the posts. By varying the length of rod (E) accurate readings can be taken at distances as short as 4 inches.

Figure 46 shows the instrument used to measure deformation of fiber along the diagonal when a load is applied to the corner of the road slab.

Used 1922-23 in a study of stresses in slabs on the Bates Experimental Road.

Designed by H. F. Clemmer, Engineer of Tests, Illinois Division of Highways, and A. C. Benkleman, Assistant Engineer of Tests, Illinois Division of Highways.

Iowa: Experiment Station, Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa.

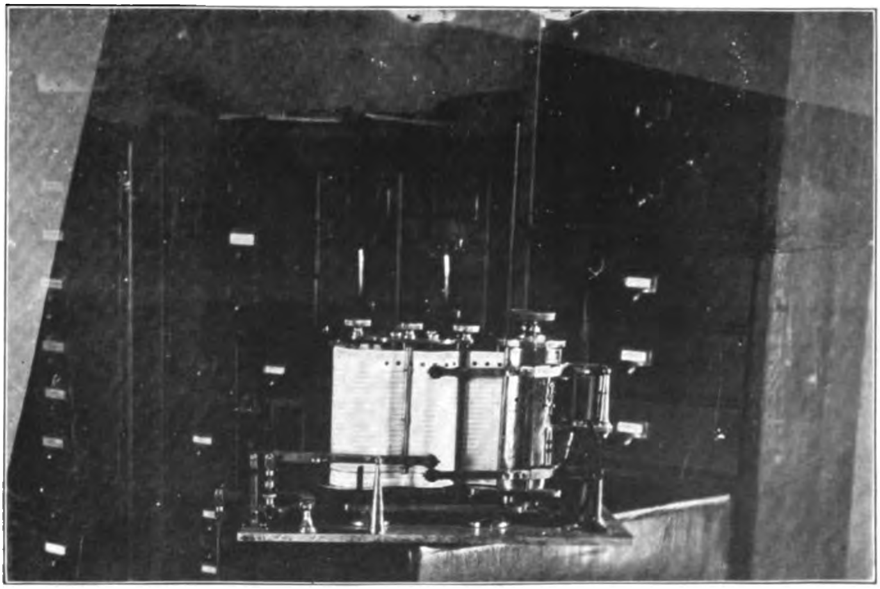


FIGURE 47.—STRAINAGRAPH MEASURING CULVERT IMPACT

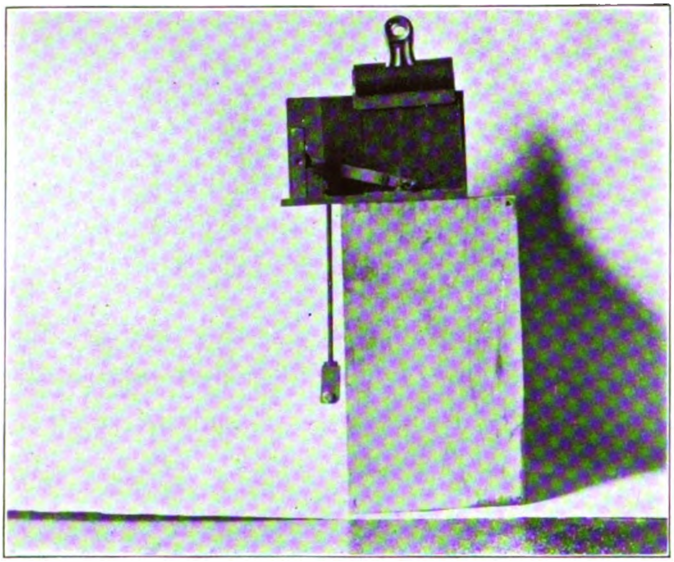


FIGURE 48.—SMOKED GLASS RECORDING DEVICE FOR MEASURING CULVERT IMPACT

ADAPTATION OF STRAINAGRAPH FOR MEASURING CULVERT IMPACT

The strainagraph, shown in Figure 47, is so arranged that the upper pen records the position of the test truck as registered by the space measuring instrument (see below). The middle pen records the elongation of spring due to impact effects which balance the beam of the platform scale. The lower pen records time in seconds, and is actuated by impulses through a pendulum clock.

When the culvert is covered with a comparatively thin fill, the device shown in Figure 48 is used to measure the impact. It consists essentially of a smoked glass plate on which is recorded the movement of a needle point fitted in the end of a lever. This device is used in place of the middle pen described above. The glass plate is held in position by a paper clamp.

The instrument was used for recording the impact data in the culvert investigations at the Iowa State College, Ames, Iowa.

SPACE MEASURING INSTRUMENT

This instrument, as shown in Figure 49, consists of a drum wound with brass wire which is fed off and on the drum evenly through a screw gear feed. The instrument is placed upon the ground with

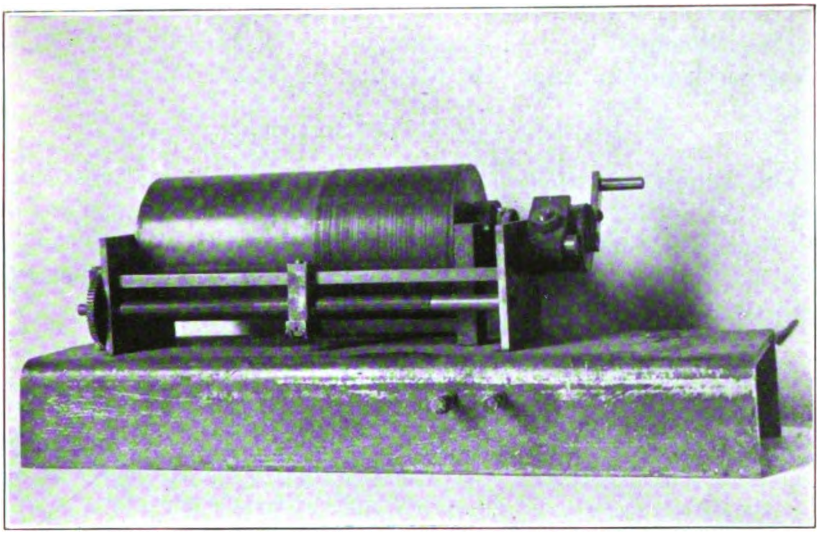


FIGURE 49.—SPACE MEASURING INSTRUMENT

the free end of the wire attached to the rear end of the truck. As the truck moves forward, the drums are rotated at the rate of one revolution for every 2-foot movement of the truck. At each revolution an electric circuit is closed, sending an impulse to the recording apparatus.

Used in connection with the culvert investigations, Iowa State College, Ames, Iowa.

The following instruments are listed as being used in the study of impact on highway bridges, a co-operative research project carried on by the Iowa State Highway Commission, Iowa Engineering Experiment Station, and the U. S. Bureau of Public Roads. From Bulletin 63, Iowa State College of Agriculture and Mechanic Arts, "Preliminary Impact Studies, Skunk River Bridge on the Lincoln Highway Near Ames, Iowa," by Almon H. Fuller.

DIRECT READING WEST EXTENSOMETER

This instrument consists of two yokes about 20 inches apart, held together by a constant-distance bar connected (with necessary freedom of motion) to the center of each yoke. The forked end of each yoke is fastened to the bridge member by means of two hardened screws. The movement, due to the deformation of the member, is transmitted to the other ends of the yokes where it is read directly by means of a Last Word dial.

The West extensometer was developed in the instrument shop of the Department of Civil Engineering, at Lafayette College, by M. L. West, mechanician, under the direction of Almon H. Fuller.

TURNEAURE EXTENSOMETER

This apparatus, which has been used extensively for measuring impact in railway bridges, is described in full in "Transactions of the American Society of Civil Engineers," Vol. XLI (1899), page 412, and in "Proceedings of the American Railway Engineering Association," Vol. 12 (1911), part 3, pages 185 to 202.

STREMMATOGRAPH (RECORDING AND SMOKED GLASS DISCS)

These instruments were developed for measuring the stress in railroad rails by a special committee of the A. S. C. E. to report on stresses in railroad tracks, and are described in the transactions of the American Society of Civil Engineers, Vol. LXXXII (1918), page 1224.

BUREAU OF PUBLIC ROADS PHOTOGRAPHIC MIRROR EXTENSOMETER

Described under Bureau of Public Roads.

BUREAU OF PUBLIC ROADS STRAIN GAGE FOR MEASURING MAXIMUM FIBRE COMPRESSION

Described under Bureau of Public Roads.

OHIO STATE UNIVERSITY MAXIMUM COMPRESSION INSTRUMENT (LOANED BY C. T. MORRIS, OHIO STATE UNIVERSITY)

COMBINATION INSTRUMENT ARRANGED BY USING THE STREMMATOGRAPH SMOKED GLASS DISCS ON A FORM OF THE WEST EXTENSOMETER

WEST STRAIN GAGE

BERRY STRAIN GAGE

Minnesota: State Highway Department.

TILE TESTING MACHINE

This machine, Figure 50, was designed with the idea of producing a portable machine which could be used on the job for testing tile. It is so constructed that it can readily be taken apart and placed in a car so that it can be moved from one job to another. It is essentially nothing more than a small press made out of channel iron and

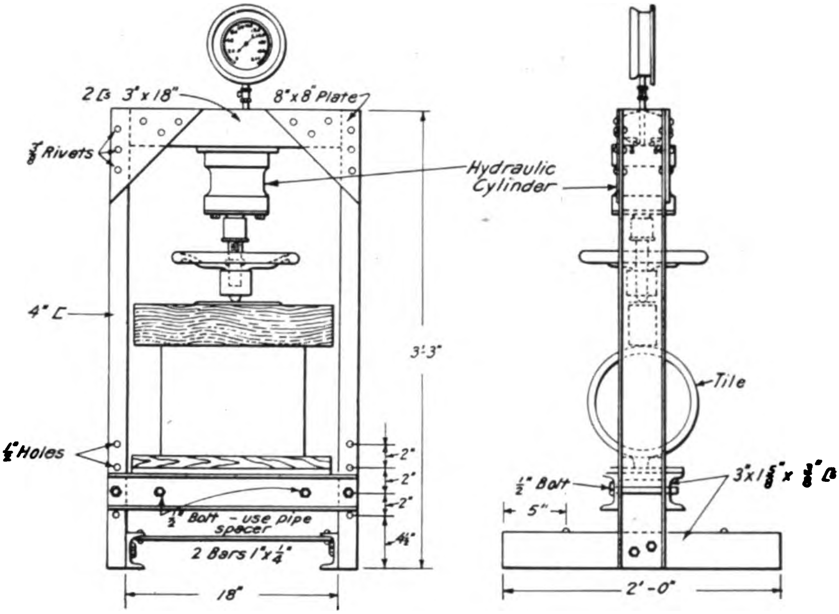


FIGURE 50.—TILE TESTING MACHINE

provided with a hydraulic cylinder and a pressure gage for measuring the load required to break the tile.

Used for field testing of tile.

Designed and constructed by the Minnesota State Highway Department.

GROUP III. APPARATUS USED IN INVESTIGATIONS OF MATERIALS

1. *Subgrade Materials.*

District of Columbia: U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING COMPARATIVE BEARING VALUE OF SOILS

This apparatus, as shown in Figure 51, consists of a container for holding the soil to be tested, a bearing block through which pressure is applied, an Ames dial for indicating the deformation of the soil, a counter-weight, system of levers, spring balance supporting the container for Ottawa sand, and a funnel and tube through which the load is applied. After the soil has been properly prepared and placed in the container, the bearing block, whose area is one square inch, is placed upon it, after which, by means of an adjusting screw, the

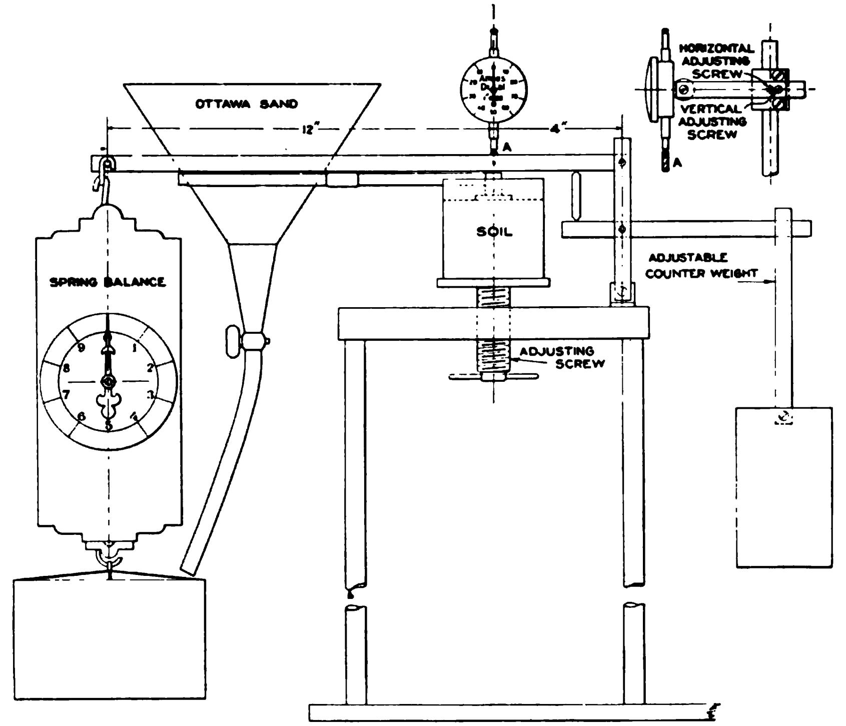


FIGURE 51.—APPARATUS FOR DETERMINING COMPARATIVE BEARING VALUE OF SOILS

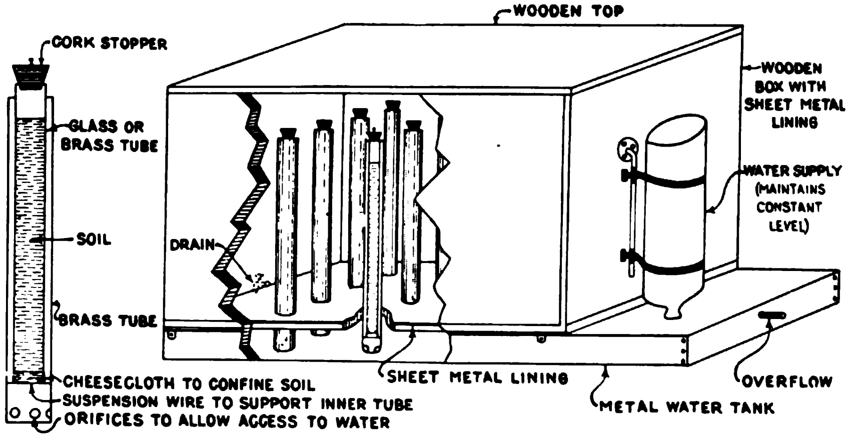

WOODEN TOP
CORK STOPPER
GLASS OR BRASS TUBE
SOIL
BRASS TUBE
DRAIN
WOODEN BOX WITH SHEET METAL LINING
WATER SUPPLY (MAINTAINS CONSTANT LEVEL)
CHEESECLOTH TO CONFINE SOIL
SUSPENSION WIRE TO SUPPORT INNER TUBE
ORIFICES TO ALLOW ACCESS TO WATER
SHEET METAL LINING
METAL WATER TANK
OVERFLOW

FIGURE 52.—APPARATUS FOR DETERMINING CAPILLARITY OF SOILS

container is raised vertically until the horizontal beam against which the top of the bearing block rests is raised 0.1 inch. The sand for applying the load is now released, and simultaneous readings of load and deformation are made for 0.1-pound increments, the maximum penetration being 0.2 of an inch. The ratio of the lever arms is such that the load readings obtained from the spring balance must be multiplied by four. For comparative purposes the bearing value of the soil is taken at that load in pounds per square inch required to produce a penetration of .1 inch.

ADAPTATION OF CENTRIFUGE FOR DETERMINING MECHANICAL ANALYSIS OF SOILS

APPARATUS FOR DETERMINING MOISTURE EQUIVALENT OF SOILS

APPARATUS FOR DETERMINING SLAKING VALUE

APPARATUS FOR DETERMINING CAPILLARITY OF SOILS

The factors given consideration in the development of this apparatus were:

(1) Simulation, in so far as practical, of the conditions characteristic in subgrade soils in the field to allow of a possible practical interpretation of the results obtained.

(2) Temperature regulation within certain limits.

(3) Accessibility of samples under test, to permit removal for observation, weighing, etc., with minimum amount of interference with the operation, and with the sample.

As shown in Figure 52, it consists of a sheet-metal lined, wooden box (A) supported over a water reservoir (B), and is so constructed as to permit simultaneous operation of a number of samples. Hollow, brass tubes (T) which are permanently set in the base of box (A) which rests upon the bottom of the reservoir (B).

These tubes, which to some extent act as auxiliary supports for box A, serve as protective jackets for and permit easy access to the soil tubes (T) inserted in them. The soil sample tubes are supported by wire strands (W) fitted in each brass tube (T), a short distance above the bottom. The wire supports are placed so that the bottoms of the soil tubes are immersed in the water which is permitted to enter the perforated brass tubes.

While in operation the tops of the tubes containing the soil sample are closed to prevent evaporation or condensation moisture. The bottom of each soil tube is covered with a cap of cheesecloth which confines the soil.

Depending upon the temperature desired, the box (A) is filled to a height just below the top of the protecting tubes (T), with water, ice, ice and salt, or similar material. The temperature of the water in the supply basin is arbitrary with the observer. In endeavoring to duplicate field conditions, it is preferable to so choose the reservoir temperature which corresponds to the temperature-depth relation in the particular subgrade.

The following determinations can be made with this apparatus:

(1) Capillary moisture contents at various temperatures.

(2) Effect of temperature change upon capillary moisture content.

(3) Effect upon the capillary moisture of difference in temperature between the soil column and the moisture supply.

The relative effect of seasonal subgrade temperature conditions upon the capillary moisture can be determined. The effect in winter when the temperature increases with depth of subgrade can be studied, and its effect in spring and summer when the temperature depth relation is more or less reversed.

Used in subgrade experiments at Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING WATER CAPACITY

APPARATUS FOR DETERMINING VOLUMETRIC SHRINKAGE

DYE ADSORPTION TUBE

The apparatus, as shown in Figure 53, consists of an adsorption tube (A), 25 cc. graduate (B), separatory funnel (C), and transfer funnel (D).

The adsorption tube (A) should measure about 6 inches by ½ inch inside diameter, and should be drawn at the lower end for a distance of 1 inch to a straight stem having ⅛-inch inside diameter. The tube is closed by a small disc or filter paper held in place by a ground glass stopper tube which should enclose the end of the stem for a distance of ¼ inch.

The separatory funnel (C) should have a capacity of 10 cc. and should be provided with a 3 mm. opening in the stop cock to allow the free passage of sand passing a 10-mesh screen.

Used to determine the dye adsorption properties of soils.

Evolved in the U. S. Bureau of Public Roads.

See Proceedings, American Society for Testing Materials, Vol. 22. Part II (1922), pp. 344-347.

Manufactured by Bausch & Lomb Optical Company, Rochester, New York.

The apparatus and methods used by the U. S. Bureau of Public Roads in determination of the physical properties of subgrade materials are described in detail in a paper entitled "Physical Properties of Subgrade Materials," presented by J. R. Boyd, before the A. S. T. M., Atlantic City, New Jersey, June 26-30, 1922.

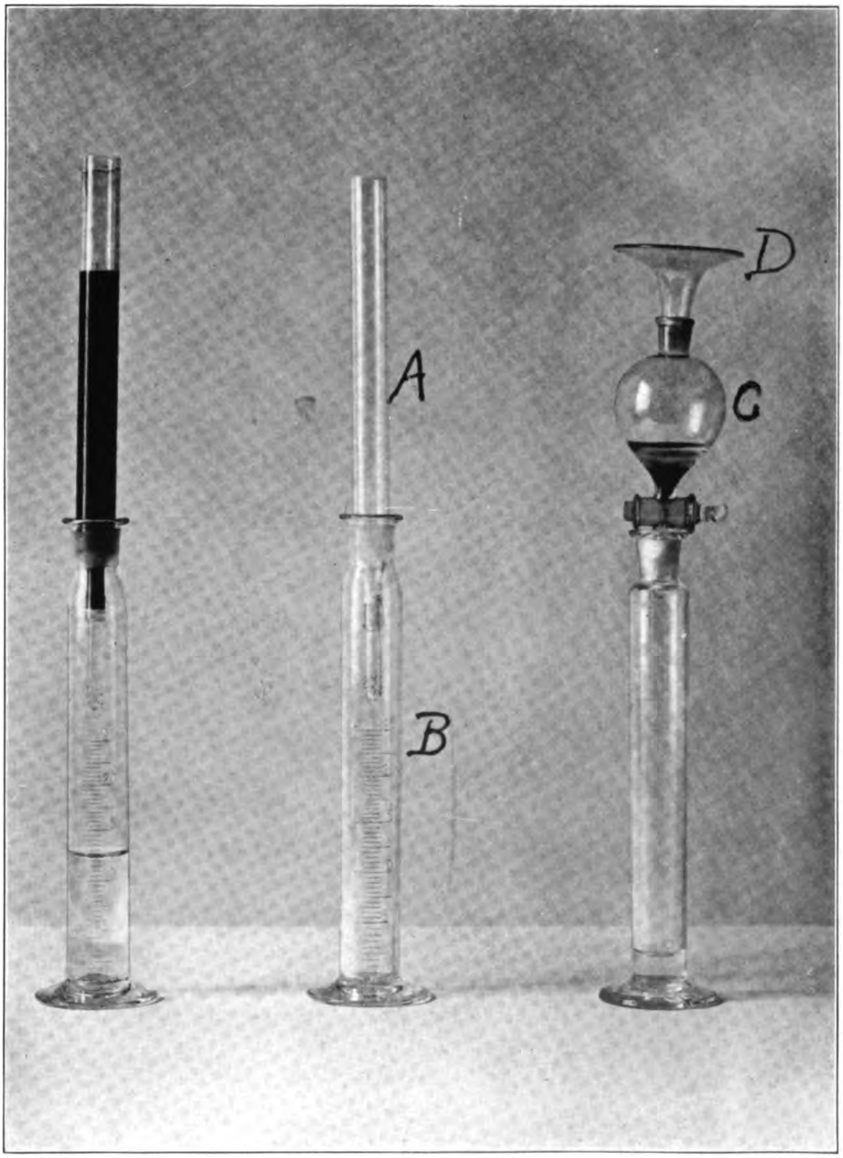


FIGURE 53.—DYE ADSORPTION TUBE

ULTRA MICROSCOPE CELL

The cell, Figure 54, consists of a small circular opening about 4 mm. in diameter and varying in depth from .025 mm. to .05 mm. and having a perfectly plain surface surrounded by an overflow trough about .10 mm. deep and 1 mm. wide. This cell is cut in a high grade optical object glass from 1.75 mm. to 2.25 mm. in thickness.

Used to count colloidal particles in liquids.

Devised in the U. S. Bureau of Public Roads.

See paper by E. C. E. Lord, entitled "Ultra-Microscopic Examination of Disperse Colloids in Bituminous Road Materials," Journal of Agricultural Research, Vol. XVII, No. 4, July 15, 1919.

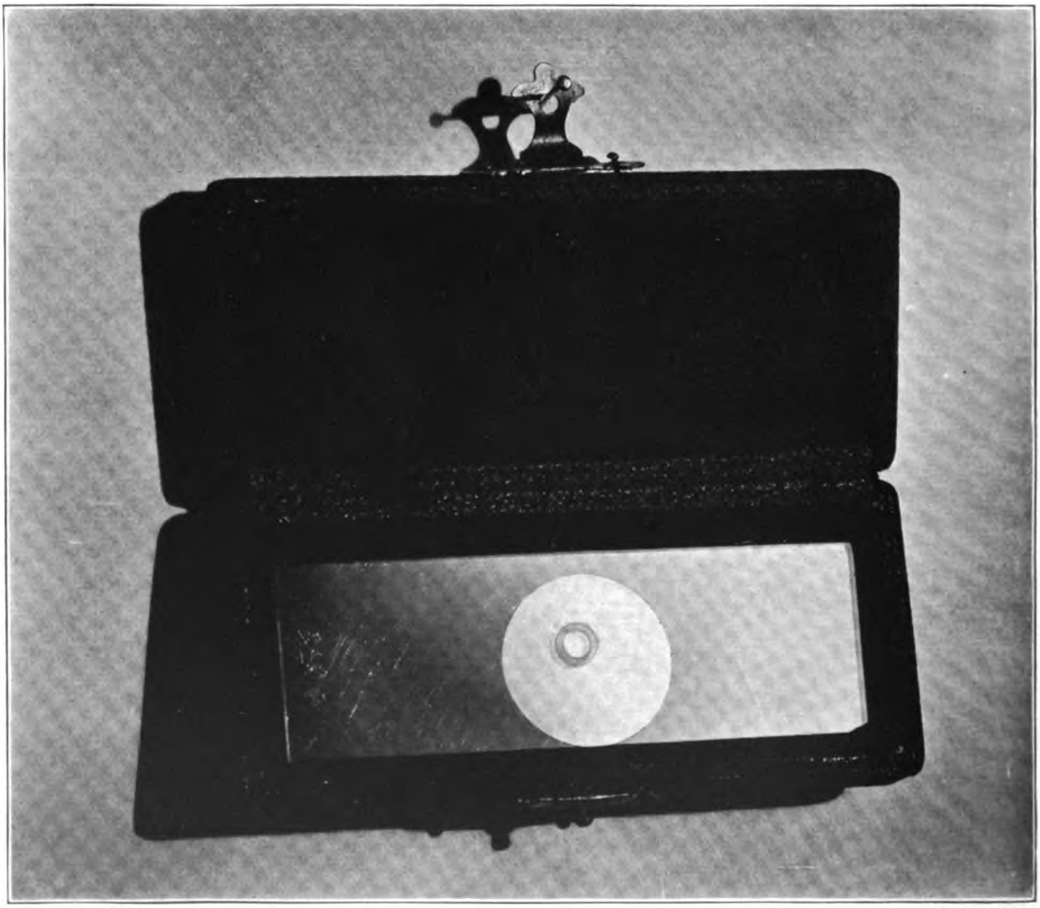


FIGURE 54. ULTRA MICROSCOPIC CELL

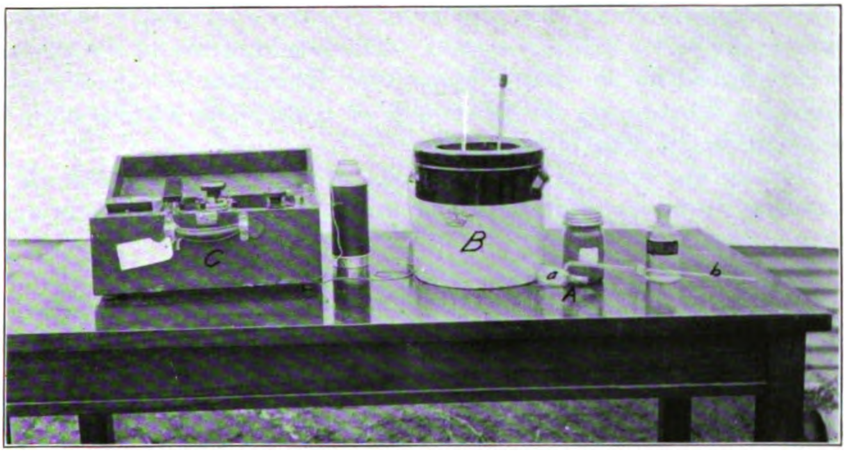


FIGURE 55.—DILATOMETER FOR MEASURING EXPANSION OF FROZEN SOIL SAMPLES

DILATOMETER FOR MEASURING EXPANSION OF FROZEN SOIL SAMPLES

This apparatus (Figure 55) consists of two parts, a dilatometer and a bath. The dilatometer (A) consists of a glass bulb (*a*) in which the soil is placed, and a graduated glass stem (*b*) on which the expansion can be read to .025 cc. A thermo couple inserted through a cork stopper serves to measure the soil temperature and also to mix the soil thoroughly. A coating of paraffin forms watertight connection with the mouth of the bulb.

The bath (B) consists of two earthenware jars placed one inside of the other. The jars have capacities of three gallons and one gallon, respectively. The space between the two jars is filled with hair, the upper part of which is waterproofed by a paraffin seal. The cooling agency is a mixture of crushed ice and salt.

The soil temperature is measured accurately to a 0.1 degree by the potentiometer.

Used at Arlington Experimental Farm, Arlington, Virginia, in subgrade investigations.

Devised by U. S. Bureau of Public Roads.

North Carolina: University of North Carolina, Chapel Hill, North Carolina.

CAPILLARY EXPERIMENT BOX

This device consists of a water-proof box 12 by 4 by 3 feet with water storage tank and an under drainage system. The soil to be tested is placed in the box and water is introduced from a storage tank to the under drainage system. The height of rise of the water is determined by an electric apparatus. The lines of vertical tap holes for determining the percentage of moisture at various elevations are in the sides of the box.

Used in the study of subgrade soils, at the University of North Carolina, in co-operation with the North Carolina State Highway Commission.

Developed by H. F. Janda, University of North Carolina.

Constructed by the University of North Carolina Construction Department.

2. Road Surface Materials.

District of Columbia: U. S. Bureau of Public Roads.

MODIFICATION IN DESIGN OF FLOW TABLE

In this modified form of the flow table, Figure 56 (see Bureau of Standards below), a single cast-iron pedestal is used to support the table instead of an angle-iron frame. Due to the possibility of the angle-iron frame being somewhat flexible and thereby possibly influencing the test results, it was thought advisable to substitute an

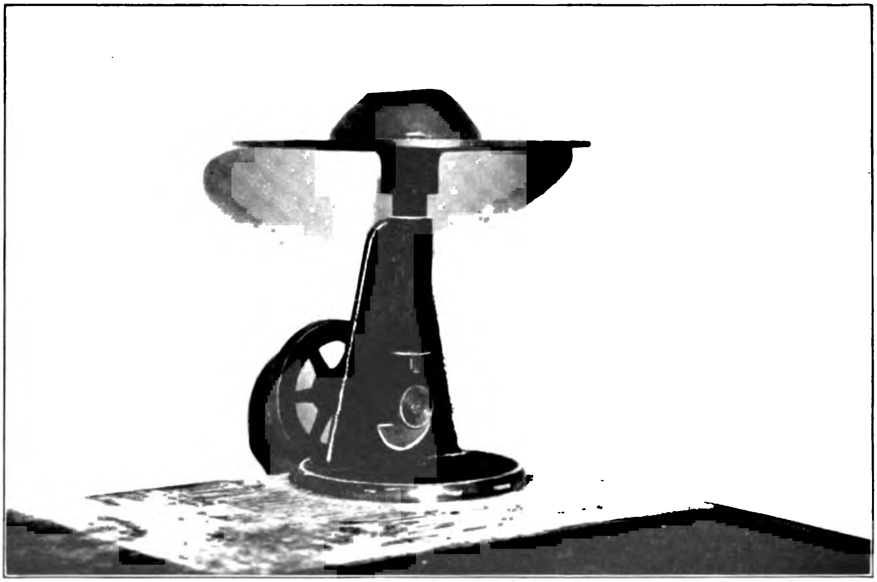


FIGURE 56.—FLOW TABLE USED BY U. S. BUREAU OF PUBLIC ROADS

absolutely rigid cast-iron base. In this type of base the table falls directly on top of the pedestal instead of upon the center of an angle-iron beam in the original design. Likewise a cast brass top is used instead of the old style tin-covered wood top.

Used in the Bureau of Public Roads investigation of consistency of concrete.

CROSS LINE MICROMETER SCALE

The scale is cut in optical glass and inserted in the eye piece of a petrographic microscope. It consists of a 1-centimeter square field divided into 100 square millimeters, one of these small areas being one per cent of the whole field occupied by a mineral.

Used to determine the volumetric percentage of minerals in thin sections of rock.

Devised in the U. S. Bureau of Public Roads.

See "Relation of Mineral Composition and Rock Structures to the Physical Properties of Road Materials," by E. C. E. Lord, U. S. Department of Agriculture Bulletin No. 348.

Manufactured by Bausch & Lomb Optical Company, Rochester, New York.

IMPACT DEVICE FOR TESTING GRAVEL IN THE FIELD

This apparatus, as shown in Figure 57, consists of two 2½-inch steel balls (A and B). The lower ball is fastened rigidly to a cast-iron anvil (C) measuring 5 inches in diameter by 1¾ inches high. The upper ball (A) is free to fall between three ⅜-inch guide rods. An adjustable stop (D), provided with a clamping nut, slides in one of the guide rods. Fastened rigidly to the upper ball is a ⅜-inch rod (E) graduated in inches, which passes through a hole in the plate supported on top of the three guide rods.

The hammer, consisting of the upper ball and the graduated rod, weighs exactly 1,200 g., while the remainder of the apparatus weighs exactly 6 kg., so that the ratio of the weight of the hammer to the weight of the anvil is 1 to 5.

The operation of the test is extremely simple. The fragment to be tested is held firmly on the lower ball between the thumb and first finger of the right hand so that its smallest diameter is vertical. The upper ball is then allowed to rest on the test specimen and the stop adjusted at the height of the fall desired, measured in inches directly on the rod. The top is then clamped in position, the upper ball raised until in contact with it and allowed to fall upon the specimen.

A very little practice will make an operator adept in holding the specimen in place without difficulty. It is possible also in almost

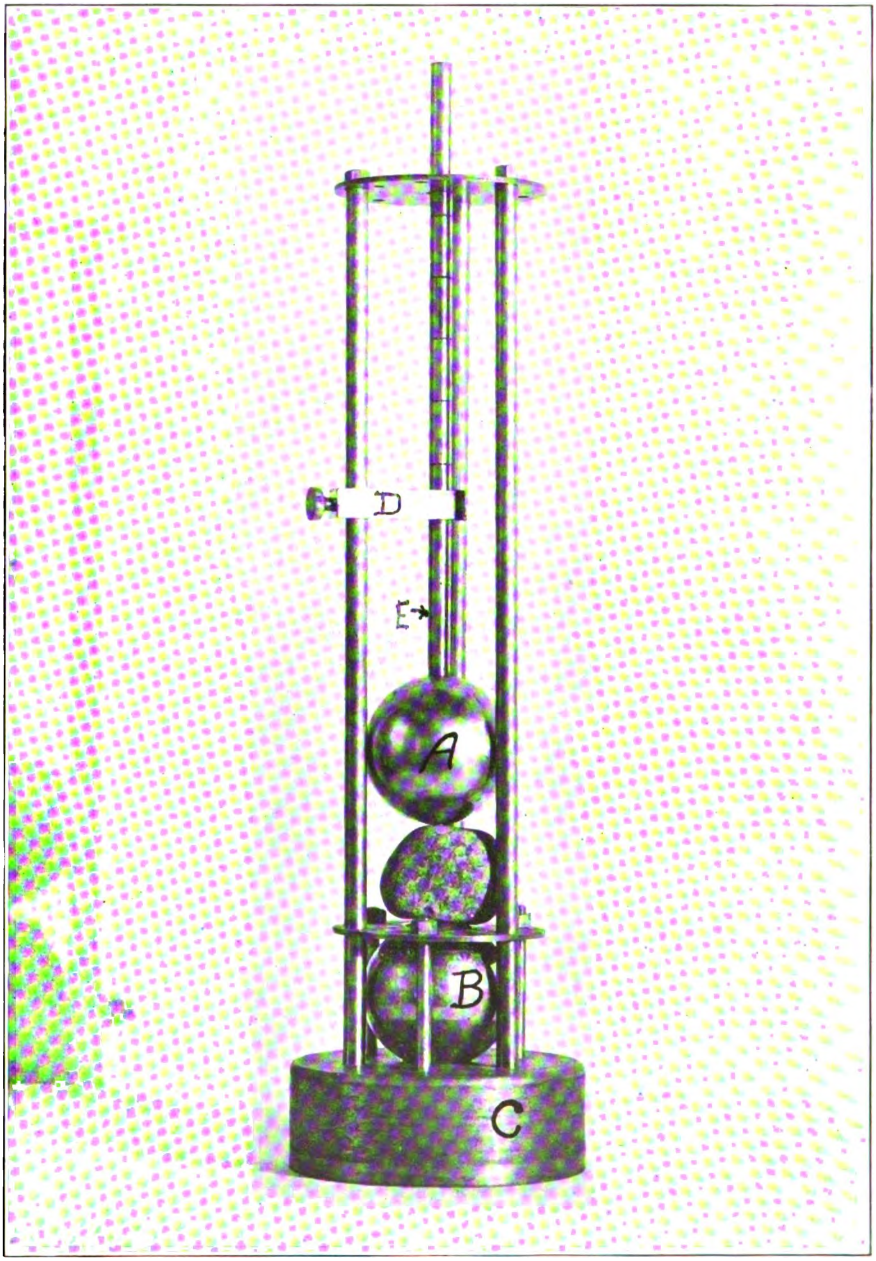


FIGURE 57.—DEVICE FOR TESTING GRAVEL IN THE FIELD

every case to secure a reasonably firm bearing on the lower ball. This may be done by trying the specimen in various positions, allowing the ball to drop in each case from a very small height, say ¼ inch, and noting the effect.

For full description and use of this apparatus see paper entitled "An Impact Test for Gravel," presented by F. H. Jackson before the American Society for Testing Materials, Atlantic City, New Jersey, June 26-30, 1922.

Designed in the U. S. Bureau of Public Roads.

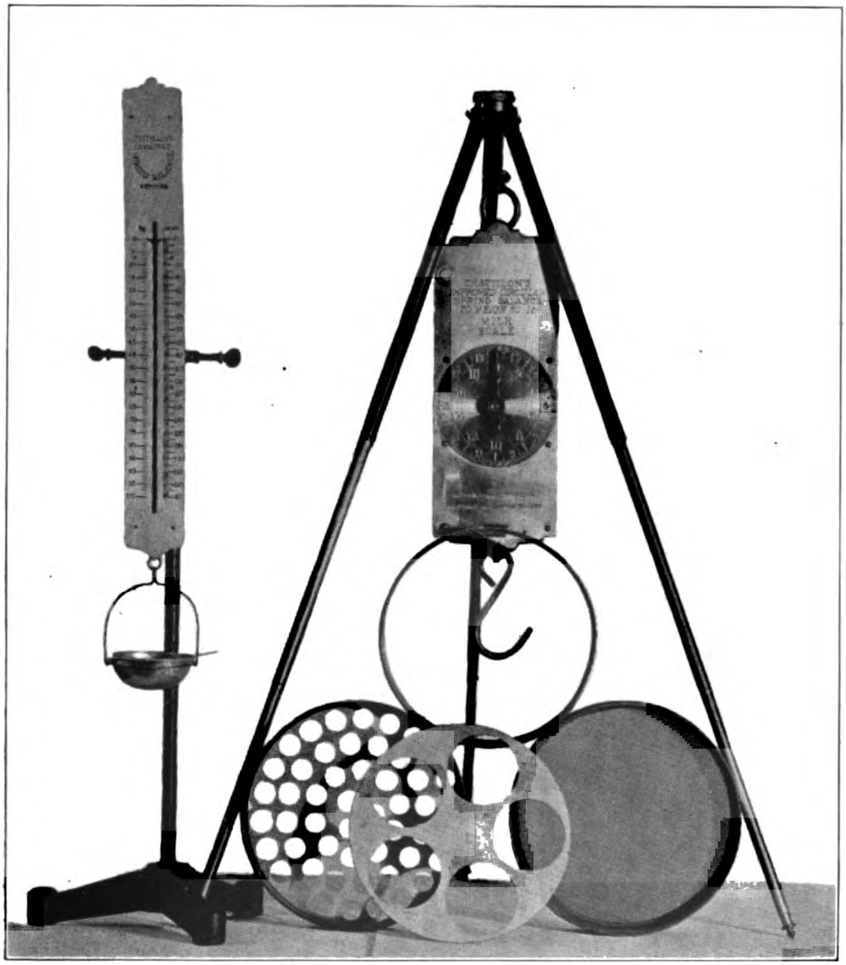


FIGURE 58.—INTERCHANGEABLE TESTING SIEVES

INTERCHANGEABLE TESTING SIEVES

As shown in Figure 58, this apparatus consists essentially of a set of rimless screens and sieves, the screens being thin, galvanized circular plates with circular perforations of various diameters and the sieves being circular brass rings, upon each of which wire mesh of the desired size has been soldered. To assemble a sieve of any desired mesh ready for use, two brass rims of such diameters that one just fits inside of the other, are used. The larger rim has a shoulder formed on the inside upon which the sieve plate rests. A rubber gasket is placed upon the top of the sieve plate to prevent fine material from escaping and the upper ring is inserted and held securely against the gasket by means of three stiff springs. For sizes ¼ inch and larger, the galvanized iron plates are used. These require no rubber gaskets. By this device it is possible to carry enough sieves and screens to make a complete mechanical analysis and still have the package occupy practically the same space as one old style laboratory sieve. For weighing aggregates, two spring-balances are used, one, a milk scale of 30 pounds capacity for coarse aggregates, and the other, a fine spring balance of 200 grams capacity for fine aggregates.

Used in field and plant inspection of aggregates.

Developed by the U. S. Bureau of Public Roads.

PORTABLE CALYX CORE DRILL OUTFIT

The arrangement of this apparatus, Figure 59, is such that the power for driving the drill is secured from the motor of the truck on which it is carried.

Used for securing samples of road surfaces in various cities and states.

Details of power transmission evolved by the U. S. Bureau of Public Roads.

Calyx Core Drill manufactured by Ingersoll-Rand Company, New York, New York.

DIAMOND POINTED TOOL FOR FACING THE ENDS OF STONE CYLINDERS

The diamond pointed tools are manufactured commercially and are similar to the tools used by automobile manufacturers for cylinder grinding. A diamond about ⅛ inch in diameter is used.

Used for preparing plane end surfaces on cylinders of stone which are to be tested in compression. It has been found by experiment

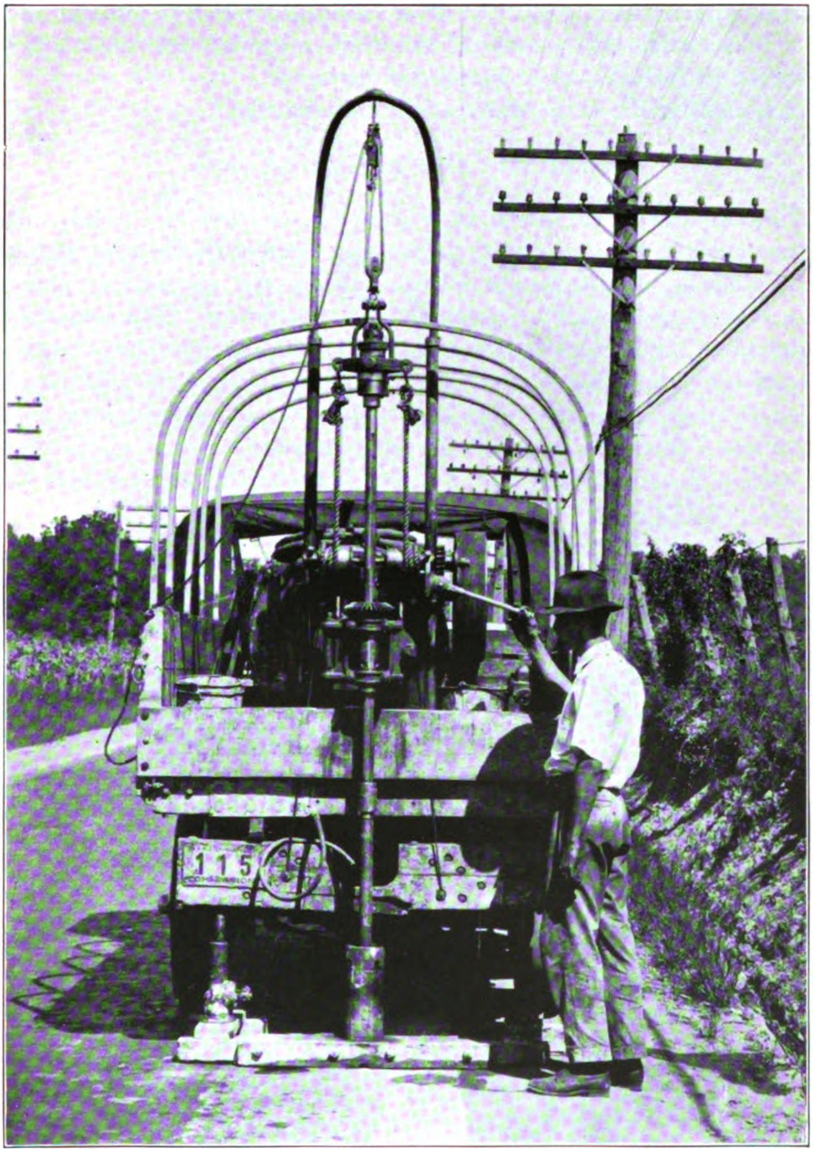


FIGURE 59.—CALYX CORE DRILL ARRANGED ON MOTOR TRUCK

that much higher crushing strengths are obtained when the ends of specimens are plane and in direct contact with bearing surfaces of the testing machine than when any form of capping is used.

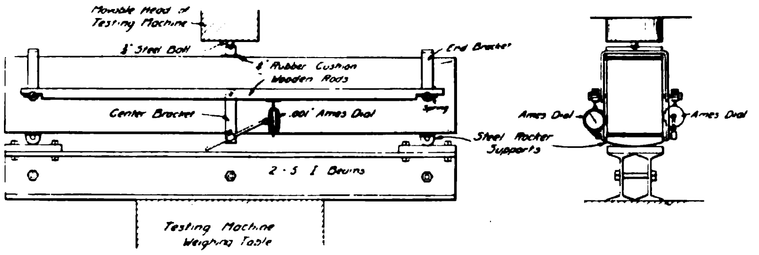
The specimen is mounted in an ordinary lathe and accurately centered so that the axis of the specimen exactly coincides with the axis of rotation of the lathe. After turning one end of the cylinder to a plane surface by means of the diamond point, the specimen is reversed in the lathe and the process repeated.

Adapted by the U. S. Bureau of Public Roads.

APPARATUS FOR TESTING BEAMS

The apparatus, as shown in Figure 60, consists of specially designed rockers having a uniform bearing against the bottom surface of the beam, and a rocker adjustment on the supporting plates. The rockers are placed under the ends of the beam. The plates are fastened to the flanges of two I-beams at such distance that the centers of the supporting rockers are 42 inches apart. The load is applied through a ¾-inch steel ball resting on a 1-inch square steel bar about 7 inches in length. To secure a more uniform application of load, a ¼-inch rubber pad is placed between the steel bar and the beam.

Special apparatus is used to measure the deflection of beams under test. This measuring device consists essentially of three U-shaped brackets of strap iron fastened to the neutral axis on each side of the beam with pointed set-screws. Two are placed directly over the end supports with the third fastened on the neutral axis at the center of the span directly under the load. This center bracket supports two Ames dials measuring to .001 inch, one on each side of the beam. Supported horizontally by the set-screws of the end brackets are two wooden bars (one on each side of the beam) against which the plungers of the Ames dials make contact. To increase



DEFLECTION MEASURING APPARATUS
CIRCULAR TRACK BEAM TESTS

FIGURE 60

the strength of the spring action of the plunger a rubber band is placed around the dial case and over the end of the plunger.

Used to test 6 by 8 by 48 inch beam specimens from the circular track, Arlington Experimental Farm, Arlington, Virginia.

Devised by the U. S. Bureau of Public Roads.

TWO-RING, TWO-DIAL COMPRESSOMETER

This compressometer (Figure 61), is of the two-ring type, supporting two Ames dials on the upper ring and two adjustable rods on the lower ring. The bronze rings are 1 inch square in cross section, and 7 inches inside diameter. These rings have two fixed steel points and one adjustable point. The points project inside the ring and have a 45° taper, which is blunt enough to prevent

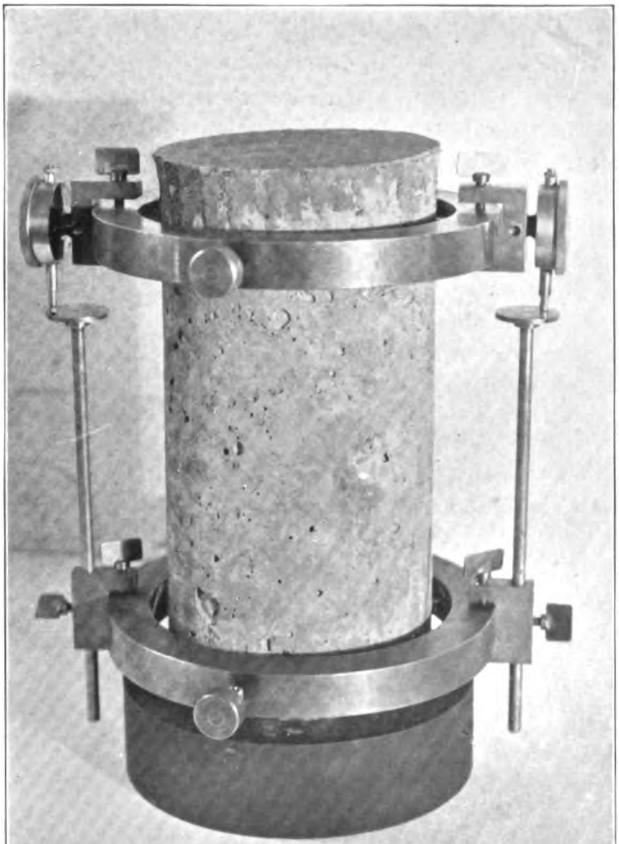


FIGURE 61.—TWO-RING TWO-DIAL COMPRESSOMETER

spalling the concrete. The points are case-hardened and set 120° apart. The adjustable point is a ⅜-inch diameter screw having 24 threads per inch. A very smooth and a close fit was secured between the threads of the screw and those in the ring. The size and weight of the rings accomplished two purposes. First, tightening the single screw of each ring until it was supported by the specimen. Second, the stiffness of the rings themselves prevents such warping as may be caused by the expansion of the cylinder under load. This was one of the main causes of error found when using the other instruments.

The upper ring supports two Ames dials, reading to .0001 inch, clamped diametrically opposite to each other to secure average deformation readings in cases of eccentric loading. The plungers of these dials rest upon the flat discs fastened to rods, which are adjustable in the clamps that are fastened to the lower ring. This arrangement allows the rings to be placed at such position on the cylinder that good support can be obtained and any convenient gage length used.

The gage length used in these tests varied from 8 to 10 inches, usually about 9 inches. As the dials permitted direct readings to .0001 inch, and it was possible to estimate tenths of a division, a unit deformation of .00001 inch per inch could be noticed. Movement of the dials occurred when the unit load did not exceed 40 pounds per square inch.

Evolved in the U. S. Bureau of Public Roads.

MODIFICATION OF THE OVERFLOW APPARATUS FOR DETERMINATION OF SPECIFIC GRAVITY OF AGGREGATES

The apparatus consists of a cylindrical glass of dimensions to accommodate a funnel of 12½-cm. diameter and depth of 15 cm. The funnel is covered by a lid and has a large inclined stem 5 cm. in diameter. A 1½-cm. hole cut 3 cm. from the top of the jar for the insertion of a special overflow tube, with a small siphon starting through capillarity of the liquid in the siphon. The object of this tube (Figure 62), is to secure a sharp cut-off and sensitive start of the flow of the liquid. For material having a large amount of dust, a deeper jar and an extended funnel stem may be used. The object of the funnel is to reduce inclusion of the air, splashing and flotation of the fine materials.

Used for determination of apparent specific gravity of mixed coarse and fine aggregates, particularly as extracted from bituminous mixtures.

Devised in the U. S. Bureau of Public Roads.

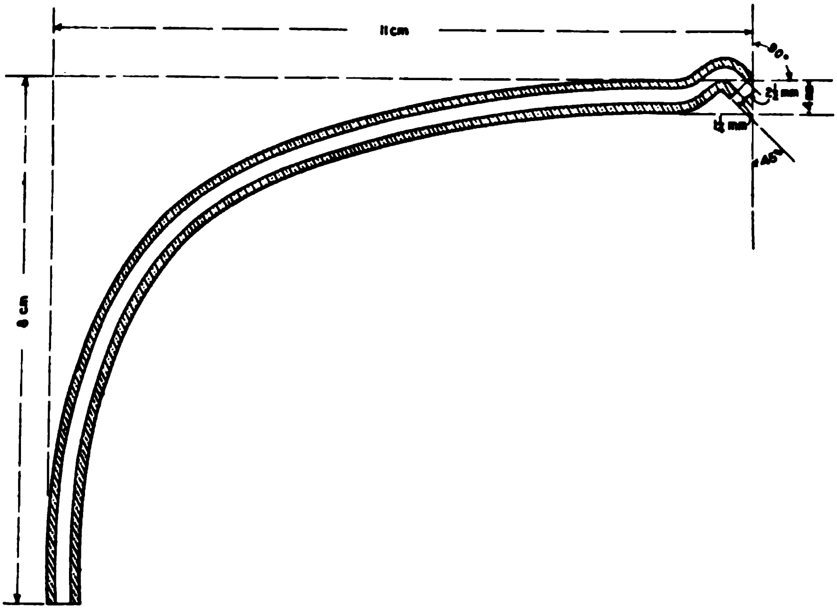


FIGURE 62.—SPECIAL OVERFLOW TUBE USED IN DETERMINATION OF SPECIFIC GRAVITY OF AGGREGATES

ELECTRICALLY HEATED MOLD FOR FORMING ASPHALTIC MIXTURE SPECIMENS

SAMPLER FOR ASPHALT PAVEMENTS

SPECIAL ADHESION CLIP FOR TESTING BITUMINOUS MATERIALS

District of Columbia: U. S. Bureau of Standards.

FLOW TABLE

This apparatus consists of a metal-covered table-top, which can be raised vertically by means of a cam working at the end of a vertical post, to which the top is attached. The height of drop can be adjusted by means of a bolt at the lower end of the shaft. A mass of concrete or mortar is molded at the center of the table in a sheet-metal mold, which has the shape of a hollow frustrum of a cone. For aggregates up to 2 inches maximum size, this mold has a height of 6 inches, and upper and lower diameters of 8 inches and 12 inches, respectively. Smaller aggregates are made up in smaller quantities, and a mold having a height of 3 inches and upper and lower diameters of 4 inches and 6 inches, is used. The mass of concrete is tamped just sufficiently to fill the form completely, the form is withdrawn and the table top is dropped fifteen times through a distance of ½ inch. The mass flattens and usually spreads concentrically. Two diameters at right angles to each other are measured, the long and short, if difference is apparent, by means of a self-reading caliper, which is so graduated that the sum of the two readings is the value for flowability. This may also be calculated by dividing the new diameter by the old and multiplying by 100.

The apparatus is used to determine the consistency or flowability of concrete.

The determination of consistency of concrete by measurement of the spread of a cylinder when dropped through different heights is described in a paper by Cloyd M. Chaplin, entitled "Method and Apparatus for Determining Consistency," published in the Proceedings of the American Society for Testing Materials, Vol. 13, 1913.

Designed and constructed by the U. S. Bureau of Standards.

For full description of the flow table and method of its use, see "Concrete Consistency Measured by Flow Table; New Apparatus Devised at Bureau of Standards Gives Accurate Measure of Flowability or Workability of Concrete," by G. M. Williams, Engineering News-Record, May 27, 1920, page 1044.

Indiana: Purdue University.

FATIGUE TESTING MACHINE FOR CEMENT MORTAR AND CONCRETE

The machine shown in Figure 63 is a mechanical device for studying the fatigue of small cement mortar and concrete beams. The frame of the machine consists mainly of 4-inch I-beams and brace rods. Mounted at the top of the frame is a ½-horsepower electric motor, drive gears and cam shaft. Connected to the cam shaft is a revolution counter and four eccentric cams, which operate the rocker arms. The concrete beams are firmly clamped in an upright position to the base of the machine by means of angle irons, and each beam supports a 4-inch I-beam, which is firmly clamped to it by similar angle irons. The machine is so constructed that movement of the rocker arms by the eccentric cams applies the load of the metal baskets and hangers alternately on the ends of the supported I-beams. This action reverses the stresses in the concrete beams periodically and causes the fatiguing action.

Devised by W. K. Hatt, Professor of Civil Engineering.

Used in Testing Materials, Laboratory, Purdue University, during 1922–23.

Designed by Engineering Experiment Station of Purdue University and U. S. Bureau of Public Roads.

See report by W. K. Hatt, Proceedings of American Concrete Institute, 1922.

Constructed by the Horat Machine Company, Lafayette, Indiana.

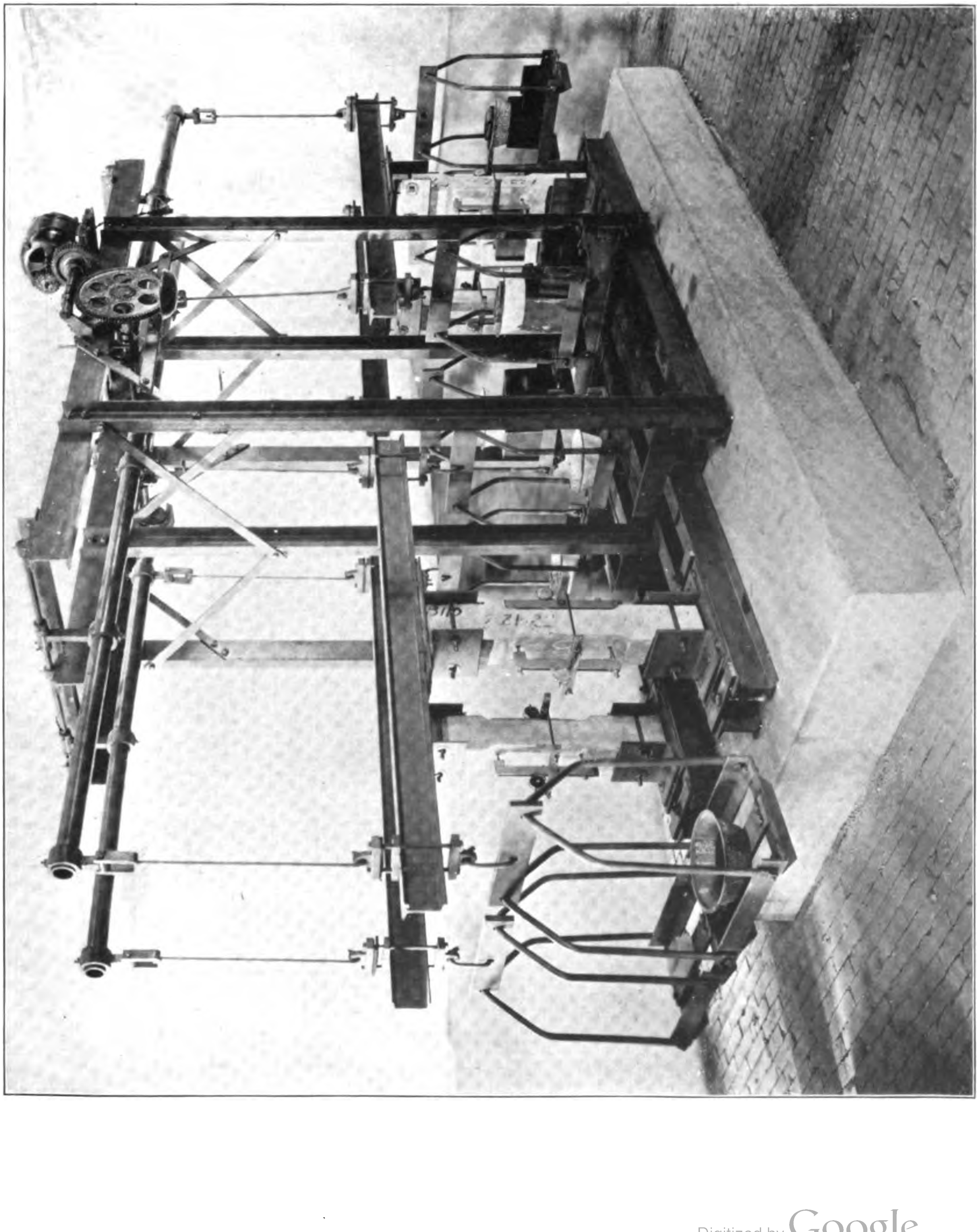


FIGURE 63.—FATIGUE TESTING MACHINE, PURDUE UNIVERSITY

BALL TEST FOR SURFACE STRENGTH OF CEMENT MORTAR AND CONCRETE

A standard steel ball ½ inch in diameter is placed on the surface of a mortar slab, which is 36 by 15 by 4 inches thick. A steel plate, 2 by 2 by 4½ inches thick, with a hole approximately ½ inch in diameter, is placed over the ball, which, therefore, projects half its diameter from the surface of the steel plate. The slab, ball, and the plate, as shown in Figure 64, are placed on the platform of a testing machine, and the load then applied on the projecting ball. This load is increased until the ball penetrates the surface of the mortar slab to one-half of its diameter, whereupon the testing head of the testing machine comes in contact with the surface of the steel plate. The resistance suddenly increases and throws up the scale beam, which is a fairly good indication that the ball has penetrated the slab to one-half of its depth.

Devised by W. K. Hatt, Professor of Civil Engineering.

Used in Testing Materials Laboratory, Purdue University. 1922–23.

Adapted by Engineering Experiment Station, Purdue University, and U. S. Bureau of Public Roads.

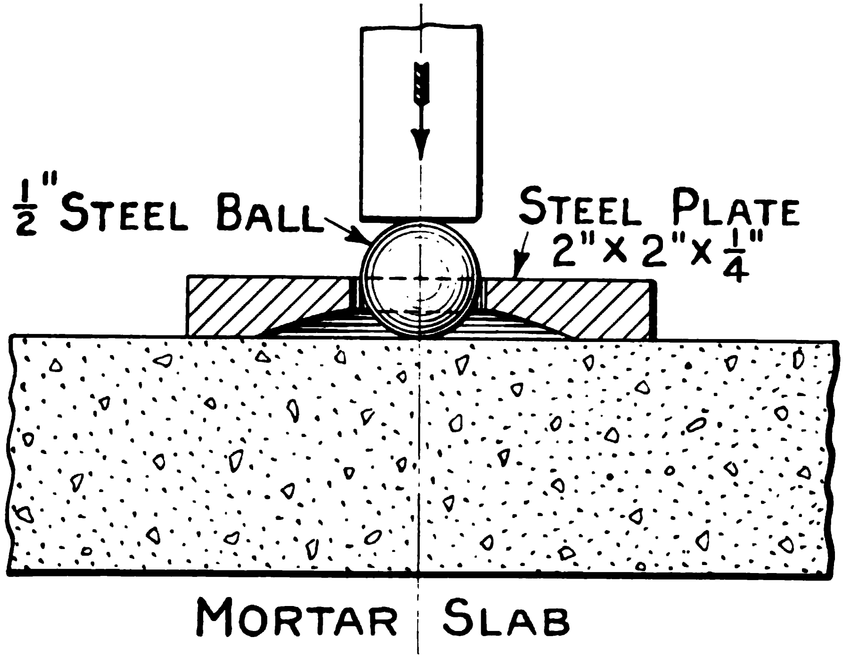


Figure 64.—BALL TEST OF MORTAR SLAB

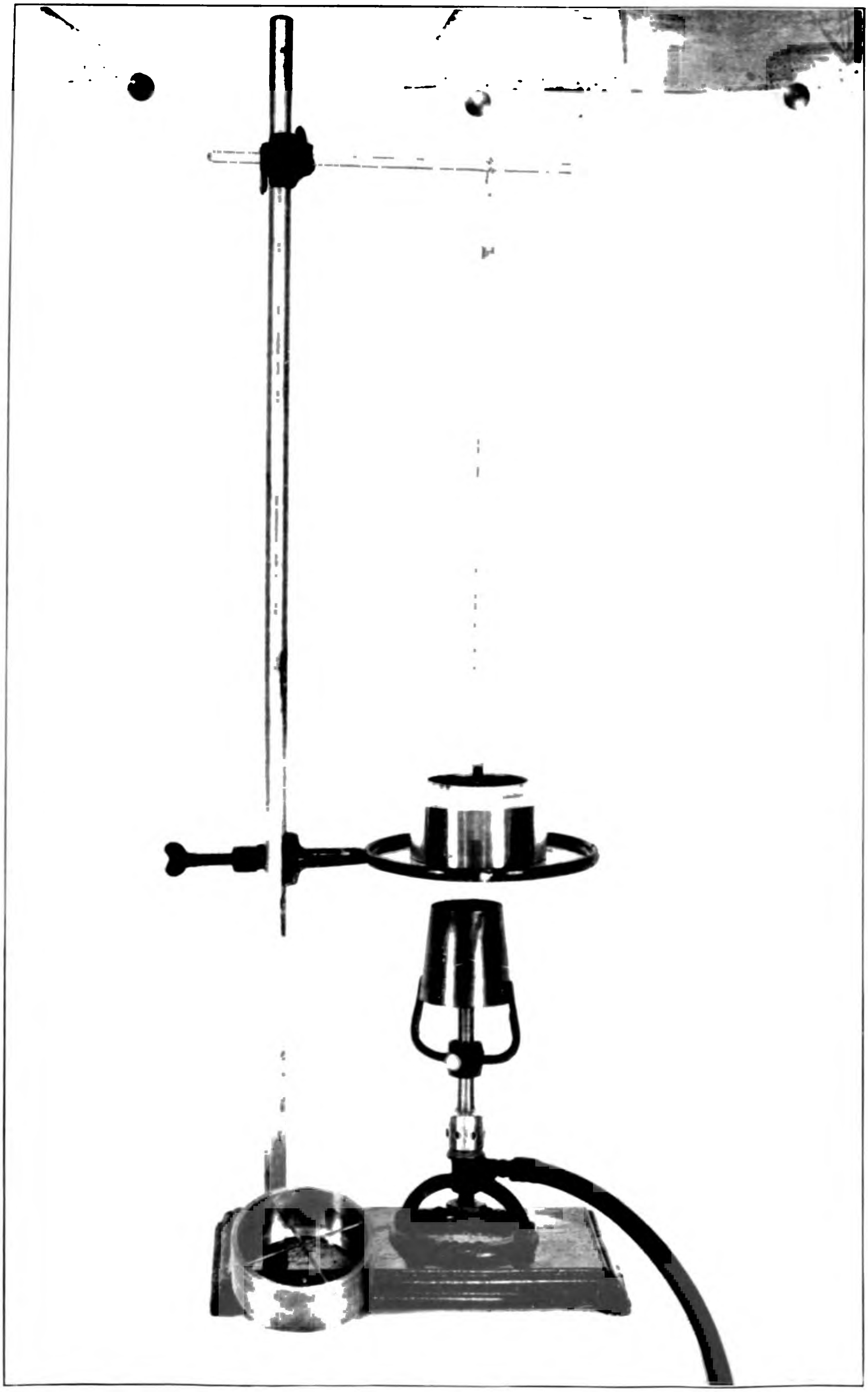


FIGURE 65.—AIR BATH FOR MAKING ANALYSIS OF ROAD OILS

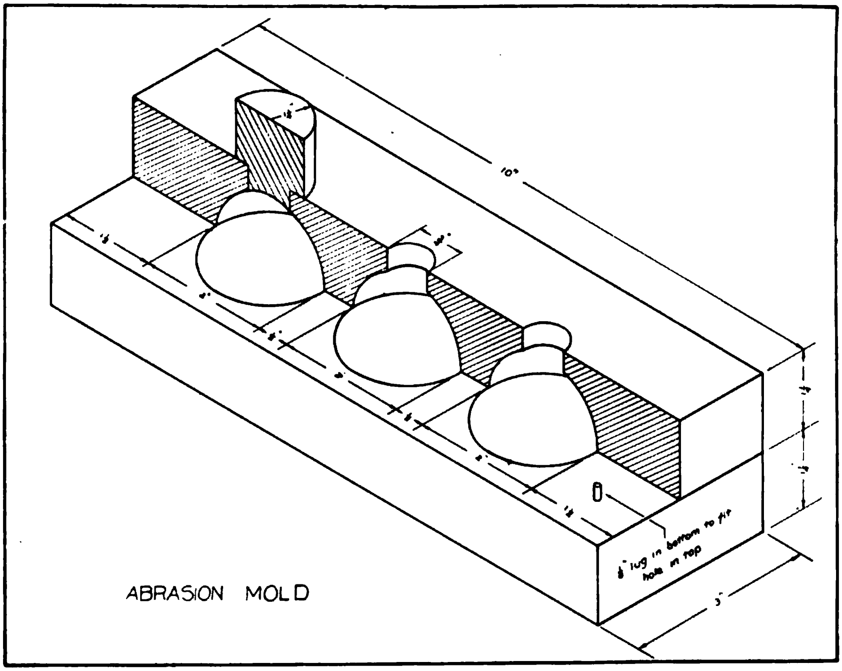


FIGURE 67

final rounding by means of a concave plug that is driven in to just the proper depth. Three spheres of mortar are cast at one time. After handling in moist air for 24 hours, the specimens are removed and placed in water for a longer curing period.

Used in abrasion test for mortar.

Designed by H. Walter Leavitt, Testing Engineer, University of Maine, College of Technology, and Maine State Highway Commission.

Constructed by University of Maine Machine Shops.

Minnesota: University of Minnesota and Minnesota State Highway Department.

SHALE TESTING APPARATUS

This apparatus consists of two galvanized iron pans, about 9 by 12 by 6 inches, and another container made out of 10-mesh sieves. This third container is constructed so as to fit inside of the galvanized iron container.

In making a shale separation, the galvanized iron container is filled with a saturated solution of zinc chloride. The rock to be tested is placed in the mesh container, which is in turn placed in the zinc chloride solution. The rock is then agitated, and the shale will rise to the top and float. The shale can then be skimmed off and the percentage of shale determined.

Used in laboratory and field tests for shale.

Devised by the Minnesota Highway Department.

Pennsylvania: State Highway Department.

ELECTRICALLY HEATED STEEL MOLDS

In these molds are compressed bituminous mixture specimens, which are to be used in tests of density, toughness, deformation, and absorption. The required weight of the heated bituminous mixture is used in order to obtain a cylinder of the desired height under a specified load. Figure 68 shows the 1¼-inch mold prior to wrapping with a resistance wire and insulation, and Figure 69 shows the 4-inch mold, with electrical equipment ready to be placed in the testing machine. By use of the resistance wire and lamp black, uniform temperatures of 100° to 475° F. may be maintained in the mold.

Designed and constructed by the Pennsylvania State Highway Department.

See report of Sub-committee No. 4 of the American Association of State Highway Officials, 1922.

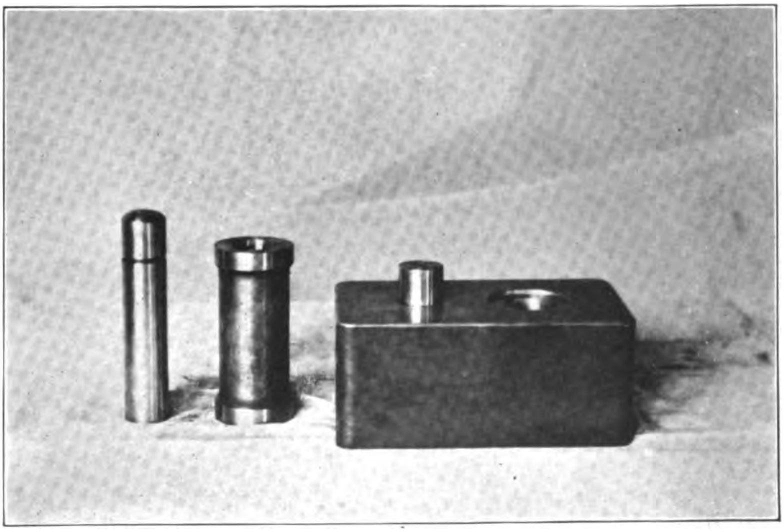


FIGURE 68.—ELECTRICALLY HEATED STEEL MOLDS WITHOUT INSULATION

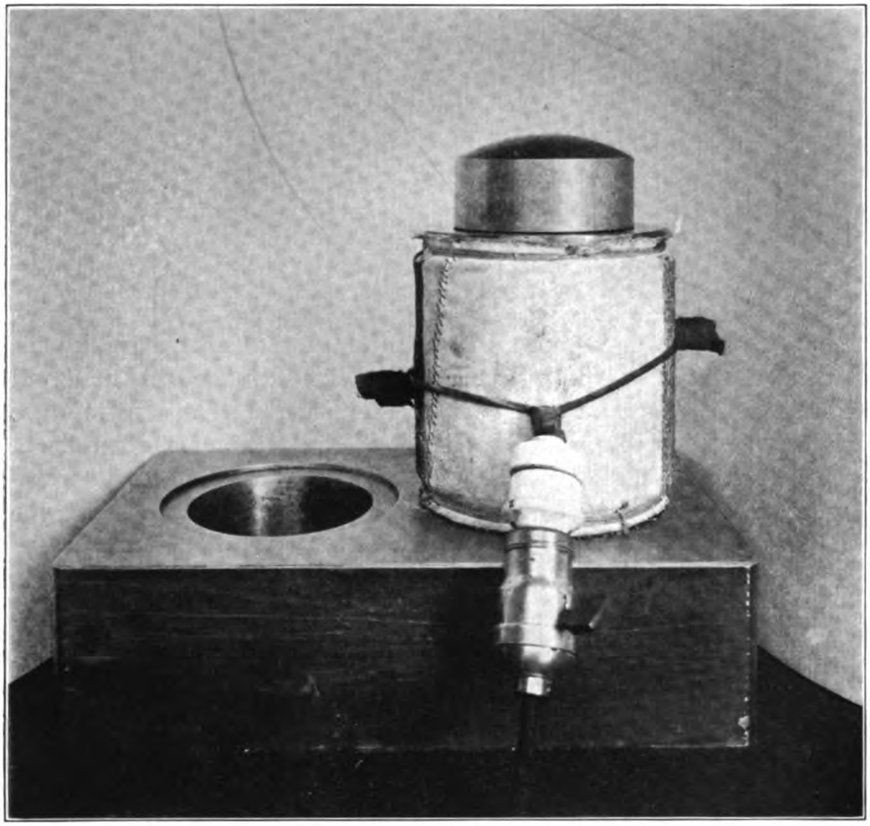


FIGURE 69.—ELECTRICALLY HEATED STEEL MOLD WITH INSULATION

IMPACT MACHINE FOR WEAR TEST ON CONCRETE

The impact machine consists of a head, which is lifted and dropped by a cam. The concrete specimen to be tested is revolved by the mechanism which drives the cam. Eight or nine hardened steel points, with which the head is fitted, are permitted by springs to adjust themselves when they come into contact with high spots on test specimens. The cam can be adjusted for any desired height of fall.

Used for wear tests on the surface of concrete cubes, cylinders, or samples taken from roads. Any size or shape of sample can be fitted in the specimen holder.

Designed by H. S. Mattimore and F. H. Rood when with the New York State Highway Commission.

See paper by H. S. Mattimore, entitled "Impact Tests on Concrete to Regulate Coarse and Fine Aggregate Qualities and Mixes for Highways," Proceedings A. S. T. M., Vol. XX, 1920, Part 11, p. 266.

SLOTTED CYLINDER FOR DEVAL ABRASION MACHINE

The slotted cylinder is similar to the regular cylinder for the Deval abrasion machine. It has 20 slots, equally spaced around the top of the cylinder, and 20 slots around the bottom, to remove the dust as fast as it forms. These slots are 1/16 inch wide on the inside, and about ⅛ inch wide on the outside of the cylinder. This cylinder is especially valuable in determining the relative value of soft aggregates, particularly those showing a loss of 8 per cent or more, in the standard cylinder. It is also used in abrasion tests of gravel.

Designed by H. S. Mattimore when with the New York State Highway Commission.

Described with photograph, Proceedings American Society for Testing Materials, Vol. XVIII, Part 11, 426-428 (1918).

STONE BREAKING MACHINE FOR DEVAL ABRASION TEST

This machine is built on the lines of a letter press. The frame, which is constructed of 4-inch channels, contains an opening about 12 inches square. A knife edge is fitted into the center of the bottom of the frame and one directly above it at the end of the movable screw. A large hand wheel (24 inches in diameter), at the top of the screw gives the required leverage to break the stone.

With this machine it is possible to break a sample of stone into cubical pieces ready for the abrasion test in ten minutes. It is also possible to secure 5 kilograms, consisting of 50 pieces, from a sample weighing about 5,500 grams, from a stone breaking like granite paving block.

Modified letter press first used by the New York State Geologist. Later improved by R. S. Greenman, New York State Engineers Office, and again by H. S. Mattimore, Pennsylvania State Highway Department.

Described in A. S. T. M. Proceedings, Vol. XX, 1920, p. 291.

Wisconsin: University of Wisconsin and State Highway Commission.

RATTLER FOR TESTING ABRASIVE RESISTANCE OF CONCRETE

The accompanying photograph, Figure 70, shows the adaptation of a standard paving brick rattler to rattler tests of 4½ by 8 by 19½-

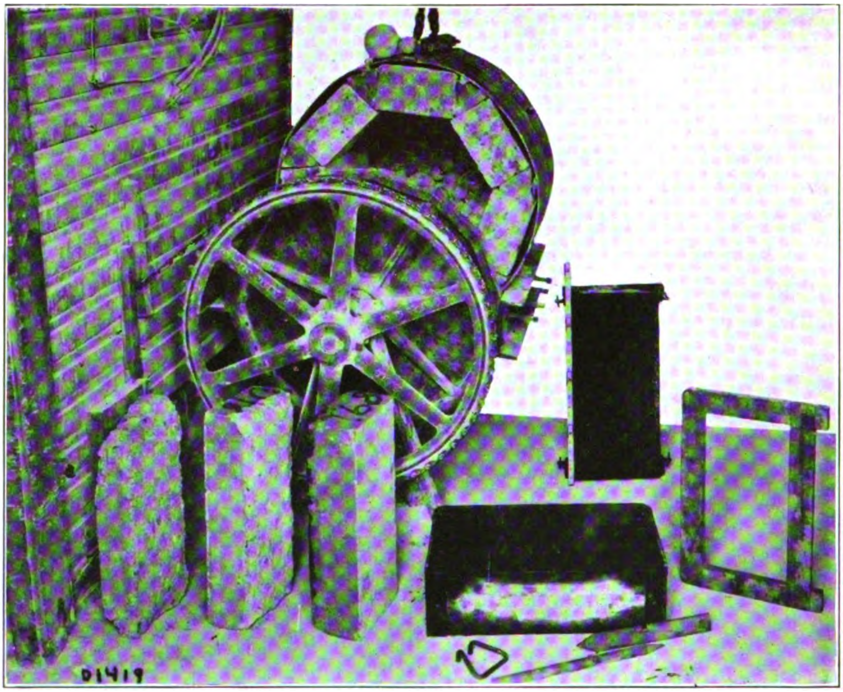


FIGURE 70.—RATTLER FOR TESTING ABRASIVE RESISTANCE OF CONCRETE

inch concrete slabs. Six concrete slabs and one wooden slab, called a "dummy," are held by two tire-like soft steel bands ¼ inch thick, in the form of a hollow heptagon. The spaces between the slabs are filled with triangular wooden blocks, wedged in place. The wooden dummy is provided with a steel face and two longitudinal slots, approximately ½ inch wide and 16 inches long. These slots emit the dust and small pebbles which accumulate during the test. The charge, which is standard for the paving rattler test, consists of 150 pounds of small cast iron shot and 50 pounds of large cast iron shot. After the specimens and charge are securely clamped in the machine, the drum is given 1,800 revolutions in a clockwise direction, and 1,800 in a counter-clockwise direction. The loss in weight during the test, the character of the surface, and the evidence of fracture in aggregate and in slab as a whole, are the criteria by which the suitability of the concrete is judged. The cast iron mold, with wooden scale beside it, illustrates the type used for making specimens in the laboratory. The pressed steel mold with wooden side, shown in the lower right foreground, is used in fabricating slabs in roads, the wooden side being set adjacent to the side form of the road. The top edge of the form is placed about one-half inch below the road surface, and the slab is marked off from the road after all operations have been completed by means of the wooden template shown at the right.

Used in the Mechanics Laboratory at the University of Wisconsin; also in the laboratory and to some extent in the field work of the Wisconsin State Highway Commission.

Designed in Mechanics Department, University of Wisconsin.

Constructed by the mechanician of the College of Engineering, University of Wisconsin.

Wyoming: State Highway Department.

IMMERSION TANK—DAMP CLOSET

This device, in which concrete briquettes are cured, was developed as a result of the investigators' inability to properly cure in still water because of the alkali in the water. If the specimens were stored in still water, the alkali crystalized on them, and, since continual evaporation increased this condition, running water was necessary. And also, since water supply pipes ran through much of the building before being available in the laboratory, the water varied considerably in temperature from time to time. This device aids in securing uniform temperatures.

Used by the Wyoming State Highway Department.

Adapted by the Wyoming State Highway Department, W. A. Norris, Testing Engineer.

Constructed by the R. Hardesty Manufacturing Company, Denver, Colorado.

BULLETIN

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CATALOGUE OF PUBLISHED BIBLIOGRAPHIES IN GEOLOGY

1896–1920

COMPILED BY

EDWARD B. MATHEWS

for

Research Information Service and Division of Geology and Geography, National Research Council

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PREFACE

The following pages have been prepared as an aid to geologists who need assistance in their survey of the vast body of observations and interpretations already on record. They represent in somewhat simplified form a continuation of the classic work *Catalogue des Bibliographies Géologiques rédigé, avec le concours des membres de la Commission bibliographique du Congrès [géologique international] par Emm. de Margerie, Paris, Gauthier-Villars et Fils, 1896,* which included references to the year 1895. The present work covers the twenty-five years, 1896–1920, and embraces 3699 titles. Like the former publication, the present volume is not a bibliography of geology but simply a catalogue of published Geological Bibliographies. The earlier collection represented the combined efforts of many geologists in various countries for a term of years; the later is a rapid compilation by the author and his efficient collaborator, Miss Grace E. Reed, Librarian of the Geological Department of the Johns Hopkins University, based upon a few libraries in Baltimore and Washington. The project was undertaken for the Research Information Service and the Division of Geology and Geography, National Research Council.

The format of references adopted in de Margerie's Catalogue with the notation of the size of page, differences in pagination, publisher, and certain other details, while highly desirable from a bibliographic standpoint, has not been followed since it would have increased the work of compilation and chances for error manyfold without any compensating gain in usefulness to the average geologist. For like reasons, a similar simplification in classification was also adopted.

The references have been gathered in three parts, each arranged alphabetically with cross references and an index of authors.

Part I includes *General Bibliographies,* Abstract journals, Indexes. and Registers of Periodicals and Society publications, Lists of Publications of Official Surveys when in permanent forms, and Bibliographies and Abstracts issued serially. This list deals with publications of interest to geologists. No attempt has been made to include such works as *Revue Bibliographique Universelle, Reader's Guide to Periodical Literature,* and other bibliographic aids well known to librarians and bibliographers.

Part II includes *Bibliographies of Special Subjects* issued separately or in connection with monographic studies. These are grouped under a single alphabet including regional, stratigraphic, and faunal rubrics. Only one master entry with cross references has been made and its choice has been determined by the major interest underlying the compilation of the bibliography. Thus, a "Bibliography of the Miocene

Mollusca of Maryland" might have been gathered to include only those works referring to Maryland or to include references to those dealing with other mollusca or Miocene deposits found useful in preparing the accompanying monograph. In such editorial selection there is necessarily a greater likelihood of error and almost certain differences of opinion. The motive has been to place the major entry where it would most probably be sought and the cross references where they might be serviceable. When the same bibliographies have been issued several times only the latest edition has been cited.

Part III includes *Personal Bibliographies and Necrologies* with attached bibliographies found in geological literature and bibliographies of geologists, mineralogists, and paleontologists issued elsewhere.

The errors of omission, transcription, and classification have been eliminated as far as possible, yet no one can realize more fully than does the compiler the fact that this collection is far from the ideal in completeness and accuracy. The extensive resources of the U. S. Geological Survey, the Congressional Library, and the Geological Department of the Johns Hopkins University probably include practically everything dealing with American geological literature, but there must be many omissions of bibliographies of foreign origin. Such, however, are chiefly those appearing in publications rarely available to American geologists. In spite of these and other less manifest imperfections, it is hoped that the compilation will prove of service to geologists generally and save them time for the conduct of their manifold and important investigations.

If the compiler had been allowed his way he would have added as joint-author the name of Miss Grace E. Reed, whose efficient and careful assistance has added greatly to whatever of value there may be in this compilation.

JOHNS HOPKINS UNIVERSITY,
March, 1923.

LIST OF ABBREVIATIONS

Aarg. naturf. Gesell., Mitth. Mitteilungen der aargauischen naturforschenden Gesellschaft.

Acad. Caes. Leop.-Car., Nova Acta. Nova Acta Academiae Caesareae Leopoldino-Carolinae Germanicae Naturae Curiosorum. *See also* Leop.-Car. deutsch. Akad. Naturf., Abh.

Acad. cienc. Madrid, Rev. Revista de la real Academia de ciencias exactas, fisicas y naturales, Madrid.

Acad. sci. St. Petersb., Bull. Bulletin de l'Académie impériale des sciences, St. Petersburg.

Acad. sci. St. Petersb., Mém. Mémoires de l'Académie impériale des sciences, St. Petersburg.

Acad. nac. Córdoba, Bol. Boletin de la Academía nacional de ciencias-en Córdoba.

Acad. nac. Córdoba, Misc. Academia nacional de ciencius, Miscelanea.

Acad. Nat. Sci. Phila., Journ. Journal of the Academy of Natural Sciences, Philadelphia.

Acad. Nat. Sci., Phila., Proc. Proceedings of the Academy of Natural Sciences, Philadelphia.

Acad. Roumaine Sect. sci., Bull. Bulletin de la Section scientifique de l'académie Roumaine.

Acad. roy. Belg., Mém. Mémoires de l'Académie royale de belgique. Classe des sciences.

Acad. roy. sci. Danemark, Bull. Bulletin de l'Académie royale des sciences et des lettres de Danemark.

Acad. roy. sci. Danemark, Mém. Mémoires de l'Académie royale des sciences et des lettres de Danemark.

Acad. sci. Cracovie, Bull. Bulletin international de l'Académie des sciences de Cracovie.

Acad. sci. Toulouse, Mém. Mémoires de l'Académie des sciences de Toulouse.

Accad. d. Lincei, Atti. Atti della reale Accademia dei Lincei.

Accad. d. Lincei, Mem. Memorie della reale Accademia dei Lincei. Classe de scienze fisiche, matematiche e naturali.

Accad. d. Lincei, Rendic. Rendiconti della reale Accademia dei Lincei. Classe de scienze fisiche, matematiche e naturali.

Accad. sci. Napoli, Rendic. Rendiconti della reale Accademia delle scienze fisiche e matematiche, Naples.

Accad. sci. nat. Catania, Atti. Atti dell' Accademia Gioenia si scienze naturali, Catania.

Accad. sci. Torino, Atti. Atti della reale Accademia delle scienze di Torino.

Accad. sci. Torino, Mem. Memorie della reale Accademia delle scienze di Torino.

Akad. Wetenschap. Amsterdam, Proc. sect. sci. K. Akademie van Wetenschappen te Amsterdam. Proceedings of the section of sciences.

Akad. Wetenschap. Amsterdam, Verh. K. Akademie van Wetenschappen te Amsterdam, Verhandelingen.

Akad. Wetenschap. Amsterdam, Versl. Verslagen der Vergaderingen van de wis-en natuurkundige Afdeeling der koninklijke Akademie van Wetenschappen, Amsterdam.

Akad. Wissensch. Berlin, Abh. Abhandlungen der königlich preussischen Akademie der Wissenschaften. Physikalisch-mathematische Klasse.

Akad. Wissensch. Berlin, Sitz. Sitzungsberichte der Königlichen preussischen Akademie der Wissenschaften.

Akad. Wissensch. München, Abh. Abhandlungen der mathematisch-physikalischen Klasse der K. B. Akademie der Wissenschaften zu München.

Akad. Wissensch. München, Sitz. Sitzungsberichte der mathematisch-physikalischen Klasse der K. B. Akademie der Wissenschaften zu München.

Akad. Wissensch. Wien, Denk. Denkschriften der kaiserlichen Akademie der Wissenschaften: Mathematisch-naturwissenschaftliche classe.

Akad. Wissensch. Wien, Sitz. Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, Wien.

Ala. Geol. Surv., Bull. Bulletin of Alabama Geological Survey.

Algeria. Serv. carte géol., Bull. Bulletin des Service de la carte géologique de l'Algérie.

Alsace-Lorraine. Geol. Landesanst., Abh. Abhandlungen zur geologischen Specialkarte von Elsass-Lothringen.

Alsace-Lorraine. Geol. Landesanst., Mitth. Mittheilungen der geologischen Landesanstalt von Elsass-Lothringen.

Alsace-Lorraine. Serv. carte géol., Bull. Bulletin des Services de la carte géologique.

Am. Acad. Arts & Sci., Mem. Memoirs of the American Academy of Arts and Sciences.

Am. Acad. Arts. & Sci., Proc. Proceedings of the American Academy of Arts and Sciences.

Am. Assoc. Adv. Sci. American Association for the Advancement of Science.

Am. Cer. Soc., Trans. Transactions of the American Ceramic Society.

Am. Geog. Soc., Bull. Bulletin of the American Geographical Society.

Am. Geol. American Geologist.

Am. Inst. M. E., Trans. Transactions of the American Institute of Mining Engineers.
Am. Journ. Sci. American Journal of Science.
Am. Min. American Mineralogist.
Am. Min. Cong. American Mining Congress.
Am. Mus. Nat. Hist., Bull. Bulletin of the American Museum of Natural History.
Am. Mus. Nat. Hist., Mem. Memoirs of the American Museum of Natural History.
Am. Nat. American Naturalist.
Am. Phil. Soc., Proc. Proceedings of the American Philosophical Society.
Am. Phil. Soc., Trans. Transactions of the American Philosophical Society.
Ann. mines. Annales des mines.
Ann. geol. balk. Annales géologiques de la péninsula balkanique.
Ann. géol. et min. Russ. Annuaire géologique et minéralogique de la Russie.
Ann. sci. nat., A. Annales des sciences naturelles; Zoologie et Paléontologie.
Arch. Lagerstättenf. Archiv für Lagerstättenforschung.
Arch. sci. phys. nat. Archives des sciences physiques et naturelles.
Argentine Rep. Min. agri., An. Anales del Ministerio de Agricultura. Sección geología, mineralogía y minería.
Argentine Rep. Dir. gen. min., Bol. Argentine Republic. Dirección general del minas, geología e hidrología. Boletin.
Ariz. Univ., Bull. Min. tech. ser. University of Arizona Bulletin. Mineral technology series.
Ark. Agri. Exp. Sta., Bull. Bulletin of the Arkansas Agricultural Experiment Station.
Assoc. franç. av. sci., C. R. Comptes-rendus de l'Association française pour l'avancement des sciences.
Augustana Lib. Publ. Augustana Library Publications.
Austral. Assoc. Adv. Sci. Australasian Association for the Advancement of Science.
Austral. Inst. Min. Eng., Proc. Proceedings of the Australasian Institute of Mining Engineers.
Austral. Inst. Min. Eng., Trans. Transactions of the Australasian Institute of Mining Engineers.
Austral. Mus., Rec. Records of the Australian Museum.
Austria. Geol. Reichsanst., Abh. Abhandlungen der kaiserlich-königlichen geologischen Reichsanstalt.
Austria. Geol. Reichsanst., Jahrb. Jahrbuch der kaiserlich-königlichen geologischen Reichsanstalt.
Austria. Geol. Reichsanst., Verh. Verhandlungen der kaiserlich-königlichen geologischen Reichsanstalt.

Baden. Geol. Landesanst., Mitth. Mittheilungen der grossherzoglich badischen geologischen Landesanstalt.
Beitr. geol. Erfors. Deutsch. Schutz. Beiträge zur geologischen Erforschung der deutschen Schutzgebiete.
Beitr. geol. Karte Schweiz. Beiträge zur geologischen Karte der Schweiz.
Beitr. geol. Karte Schweiz, Geotech. ser. Beitrage zur geologischen Karte der Schweiz. Geotechnische Serie.
Beitr. Paläont. Oesterr.-Ung. Beiträge zur Paläontologie und Geologie Österreich-Ungarns und des orients.
Beitr. z. Geophys. Beiträge zur Geophysik.
Berg-hütt. Jahrb. Berg- und hüttenmannisches Jahrbuch der k. k. montanistische Hochschulen zu .Leoben und Príbram.
Bergens Mus. Aarb Bergens Museums Aarbok (or Aarberetning).
Bergw. Mitt. Bergwirtschaftliche Mitteilungen.
Böhm. Gesell. Wissen., Sitz. Sitzungsberichte der königl.-böhmischen Gesellschaft der wissenschaften. Mathematisch-naturwissenschaftliche Klasse.
Bol. nat. Siena. Bollettino del naturalista, Siena.
Boston Soc. Nat. Hist., Mem. Memoirs of the Boston Society of Natural History.
Boston Soc. Nat. Hist., Proc. Proceedings of the Boston Society of Natural History.
Brazil. Comm. est. min., Final Rept. Brazil, Commissao de estudos das minas de carvao de pedra do Brazil. Final Report.
Brazil. Serv. geol. Brazil, Serviço geologico e mineralogico.
Brit. Assoc. Adv. Sci., Rept. Report of British Association for the Advancement of Science.
Brit. Columbia Dept. Mines, Bull. Bulletin of Department of Mines, British Columbia.
Buffalo Soc. Nat. Sci., Bull. Bulletin of the Buffalo Society of Natural Sciences.
Bull. Am. Paleont. Bulletins of American Paleontology.

Cal. Acad. Sci., Mem. Memoirs of the California Academy of Sciences.
Cal. Acad. Sci., Proc. Proceedings of the California Academy of Sciences.

Cal. State Min. Bur. Bull. Bulletin of the California State Mining Bureau.
Cal. Univ., Mem. Memoirs of the University of California.
Cal. Univ., Pub. in Geol. University of California Publications in Geology.
Cal. Univ. Dept. Geol., Bull. University of California Publications. Bulletin of the Department of Geology.
Cambridge Phil. Soc., Proc. Proceedings of the Cambridge Philosophical Society.
Canad. Inst., Trans. Transactions of the Canadian Institute.
Canad. Min. Inst., Bull. Monthly Bulletin of the Canadian Mining Institute.
Canad. Min. Inst., Journ. Journal of the Canadian Mining Institute.
Canad. Min. Inst., Trans. Transactions of the Canadian Mining Institute.
Canad. Min. Journ. Canadian Mining Journal.
Canad. Rec. Sci. Canadian Record of Science.
Canada Comm. Con. Commission of Conservation, Canada.
Canada Dept. Int., Mines Br. Canada Department of the Interior. Mines Branch.
Canada Dept. Mines, Mines Br., Bull. Bulletin of Canada Department of Mines, Mines Branch.
Canada Geol. Surv., Ann. Rept. Annual Report of the Geological Survey of Canada.
Canada Geol. Surv., Mem. Memoirs of the Geological Survey of Canada.
Canada Geol. Surv. Cont. Can. Paleont. Contribution to Canadian paleontology.
Canada Geol. Surv., Vict. Mem. Mus., Bull. Canada Geological Survey, Victoria Memorial Museum, Bulletin.
Carnegie Inst. Wash., Publ. Publications of the Carnegie Institution, Washington.
Carnegie Mus., Pittsburgh, Ann. Annals of the Carnegie Museum, Pittsburgh.
Carnegie Mus. Pittsburgh, Mem. Memoirs of the Carnegie Museum, Pittsburgh
Centralb. f. Min. Centralblatt für Mineralogie, Geologie und Palaeontologie.
Chicago Acad. Sci., Bull. Bulletin of the Chicago Academy of Sciences.
Chicago Acad. Sci., Sp. Publ. Special Publications of the Chicago Academy of Sciences.
China. Geol. Surv., Bull. Bulletin of the Geological Survey of China.
Christiania Vidensk.-Forhandl. Christiania Videnskabs-selskabs Forhandlingar.
Cinn. Soc. Nat. Hist., Journ. Journal of the Cincinnati Society of Natural History.
Colo. Geol. Surv., Bulletin. Bulletin of the Colorado Geological Survey.
Colo. Geol. Surv., Rept. Report of the Colorado Geological Survey.
Colo. Sci. Soc., Proc. Proceedings of the Colorado Scientific Society.
Colo. Univ. Studies. University of Colorado Studies.
Columbia Univ. Dept. Geol., Contr. Contributions from the Geological Department of Columbia University.
Com. invest. paleont. Comisión de investigaciones paleontológicas y prehestoricas. Mémoria.
Comm. State Reserv. Niagara, Ann. Rept. Annual Report of the Commissioners of the State Reservation at Niagara.
Congrès géologique international. *See* Int. Geol. Cong.
Connect. Acad. Sci., Trans. Transactions of the Connecticut Academy of Arts and Sciences.
Connect. Geol. Surv., Bull. Connecticut State Geological and Natural History Survey. Bulletin.
Cuba. Sec. agri., Bol. esp. Cuba, Secretaria de Agricultura, comercio y trabajo. Boletin especial.
Cuba. Sec. agri., Bol. de minas. Cuba Secretaria de Agricultura, comercio y trabajo. Direccion de montes y minas. Boletín de minas.

Dansk geol. foren., Meddel. Meddelelser fra Dansk geologisk forening.
Danske videns. selsk., Skrifter. K. Danske Videnskabernes Selskab, Copenhagen. Naturvidenskabelig og mathematish afdeling. Skrifter.
Denison Univ., Sci. Lab., Bull. Bulletin of the Scientific Laboratories of Denison University.
Denmark. Geol. undersøg. Danmarks Geologiske undersøgelse.
Deutsch. geol. Gesell., Zeit. Zeitschrift der deutschen geologischen Gesellschaft.
Deutsch. u. oesterr. Alpenver., Zeit. Zeitschrift des deutschen und österreichischen Alpenvereins.

Eclogae Geol. Helv. Eclogae geologicae Helvetiae.
Econ. Geol. Economic Geology.
Edinb. Geol. Soc., Trans. Transactions of the Edinburgh Geological Society.
Egypt Geol. Surv., Rept. Egypt Geological Survey. Report.
Elisha Mitchell Sci. Soc., Journ. Journal of the Elisha Mitchell Scientific Society.
Eng. & Min. Journ. Engineering and Mining Journal.

Erdbeben-Komm. Akad. Wissensch., Wien. Mitth. Mittheilungen der Erdbeben-Kommission der k. Akademie der Wissenschaften in Wien.
Fennia. Fennia: Bulletin de la Société de géographie de Finlande.
Field Columbian Mus. Field Columbian Museum. Geological Series.
Finland. Comm. géol., Bull. Bulletin de la Commission géologique de Finlande.
Florida Geol. Surv., Ann. Rept. Annual Report of the Florida State Geological Survey.
Földt. Közl. Földtani Közlony, Budapest.
Fortschr. Min. Krist. Petrogr. Fortschritte der Mineralogie, Kristallographie und Petrographie.
France. Serv. carte géol., Bull. Bulletin des Services de la carte géologique de la France.
France. Serv. carte géol., Mém. Mémoires pour servir à l'explication de la carte géologique detaillée de la France.
France. Serv. top. souter., Études gîtes min. Col. franç. Études des gîtes minéraux de la France. Colonies françaises.
Frank. Inst., Journ. Journal of the Franklin Institute.
Frans Josefs-Akad., Abh. Abhandlungen der tschechischen Kaiser Frans Josefs-Akademie für Wissenschaft, Literatur und Kunst.
Fysiogr. Sällsk. Lund Handl. Kongliga fysiografiska Sällskapets i Lund Handlingar.

Geogr. Abh. Geographisches Abhandlungen.
Geogr. Ann. Geografiska annaler, Stockholm.
Geogr. Jahresb. Geographischer Jahresbericht aus Österreich.
Geogr. Journ. Geographical Journal, London.
Geogr. Rev. Geographical Review.
Geogr. Gesell. Wien, Mitth. Mittheilungen der geographischen Gesellschaft in Wien.
Geogn. Jahresh. Geognostische Jahreshefte.
Geol. Assoc., Proc. Proceeding of the Geologists' Association.
Geol. Fören. Stockh. Förh. Geologiska föreningens i Stockholm förhandlingar.
Geol. Hung. Geologica Hungarica.
Geol. Karte Schweiz., Erläut. Geologische Karte der Schweiz, Erläuterungen.
Geol. Mag. Geological Magazine.
Geol.-mijn. Genoots. v. Neder. en Kol. Verhandelingen van het geologisch-mijn-bouwhundig Genootschap voor Nederland en Kolonien.
Geol. Rundsch. Geologische Rundschau.
Geol. Soc. Am., Bull. Bulletin of the Geological Society of America.
Geol. Soc. Glasgow, Trans. Transactions of the Geological Society of Glasgow.
Geol. Soc. Hull, Trans. Transactions of the Geological Society of Hull.
Geol. Soc. London, Q. J. Quarterly Journal of the Geological Society of London.
Geol. Soc. S. Afr., Trans. Transactions of the Geological Society of South Africa.
Geol. Soc. Tokyo, Journ. Journal of the Geological Society of Tokyo.
Geol. u. paläont. Abh. Geologische und palaeontologische Abhandlungen.
Geol. Zentralbl. Geologische Zentralblatt.
Georgia Geol. Surv., Bull. Bulletin of the Georgia Geological Survey.
Gesell. Erd. Berlin, Zeit. Zeitschrift der Gesellschaft für Erdkunde zu Berlin.
Gesell. von Freund. Gera, Jahresb. Jahresbericht der Gesellschaft von Freunden der Naturwissenschaft in Gera.
Gesell. Wissen. Göttingen, Abh. Abhandlungen der königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse.
Gesell. Wissen. Göttingen, Nachr. Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse.
Giorn. geol. prat. Giornale di geologia pratica.
Glasgow Univ. Geol. Dept., Papers. Papers from the Geological Department Glasgow University.
Gt. Brit. Geol. Surv., Mem. Memoirs of Geological Survey of Great Britain.
Gt. Brit. Geol. Surv., Spec. Repts. Min. Res. Memoirs of the Geological Survey. Special Reports on the Mineral Resources of Great Britain.
Grenoble, Univ., Ann. Annales de l'université de Grenoble.
Grenoble, Univ. Lab. géol., Trav. Travaux du laboratoire de géologie de l'université Grenoble.
Groningen, Min.-geol. Inst., Mitth. Mittheilungen aus dem mineralogisch-geologischen Institut der Reichs-Universität zu Groningen.

Handb. reg. Geol. Handbuch der regionalen Geologie.
Harvard Univ. Mus. Comp. Zool., Bull. Bulletin of the Museum of Comparative Zoology at Harvard College. Geological series.

Hesse. Geol. Landesanst., Abh. Abhandlungen der grossherzoglich hessischen geologischen Landesanstalt zu Darmstadt.
Hist. Monatsbl. Posen. Historische Monatsblätter für die Provinz Posen.
Hungary. Geol. Anst., Jahrb. Jahrbuch der königlich ungarischen geologischen Anstalt.
Hungary. Geol. Anst., Mitth. Mittheilungen aus dem Jahrbuche der königlich ungarischen geologischen Anstalt.

Illinois Geol. Surv., Bull. Illinois State Geological Survey. Bulletin.
Imp. Inst. Mon. Imperial Institute Monographs on Mineral Resources with special reference to the British Empire.
India Geol. Surv., Mem. Memoirs of the Geological Survey of India.
India Geol. Surv., Pal. Ind. Geological Survey of India. Palaeontologia indica.
India Geol. Surv., Rec. Records of the Geological Survey of India.
Indiana Dept. Conserv. Indiana Department of Conservation. Division of Geology. Publication.
Indiana Dept. geol., Ann. Rept. Indiana Department of Geology and Natural Resources. Annual Report.
Indo-China. Serv. géol., Bull. Bulletin du Service géologique de l'Indochine.
Indo-China. Serv. géol., Mém. Mémoires du Service géologique de l'Indochine.
Inst. Cat. Hist. Nat., Treb. Treballs de la institvcio Catalana d'historia natvral. Barcelona.
Inst. M. E., Trans. Transactions of the Institution of Mining Engineers.
Inst. Petrol. Tech., Journ. Journal of the Institution of Petroleum Technologists.
Int. Geog. Cong., Rept. Report of the International Geographical Congress.
Int. Geol. Cong. International Geological Congress.
Iowa Acad. Sci., Proc. Proceedings of the Iowa Academy of Science.
Iowa Geol. Surv. Iowa Geological Survey.
Iowa Univ. Lab. Nat. Hist., Bull. Bulletin of the Laboratory of Natural History of University of Iowa.
Ireland Geol. Surv., Mem. Memoirs of the Geological Survey of Ireland.
Irish Nat. Irish Naturalist.
Italy. Com. geol., Boll. Bollettino del R. Comitato geologico d'Italia.
Italy. Com. geol., Mem. carta geol. Italy R. Comitato geologico. Memorie descrittive della carta geologica d'Italia.

J. H. U. Circ. Johns Hopkins University Circulars.
Jaarb. Mijnw. Ned. O.-Ind. Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië.
Jahrb. f. Berg.- u. Hüttenw. Sachsen. Jahrbuch für das Berg- und Hüttenwesen in Königreiche Sachsen.
Journ. Geol. Journal of Geology.

Kansas Acad. Sci., Trans. Transactions of the Kansas Academy of Science.
Kansas Geol. Surv. The University Geological Survey of Kansas.
Kansas Univ., Sci. Bull. Science Bulletin of the University of Kansas.
Ky. Dept. Geol. & Forest., Bull. Bulletin of the Department of Geology and Forestry of Kentucky.
Ky. Geol. Surv. Kentucky Geological Survey.

La Plata Mus., An. Sec. geol. y min. Anales del Museo de la Plata. Seccion geológica y mineralógica.
La Plata Mus., Rev. Revista del Museo de la Plata.
Lausanne, Univ. Lab. géol., Bull. Bulletin des laboratoires de géologie, géographie physique, minéralogie et paléontologie de l'Université de Lausanne.
Leiden. Geol. R. Mus., Samml. Sammlungen des geologischen Reichs-Museums in Leiden.
Leop.-Car. deutsch. Akad., Abh. Abhandlungen der kaiserlichen Leopoldinisch-Carolinischen deutschen Akademie der Naturforscher. *See also* Acad. Caes. Leop.-Car., Nova Acta.
Linnean Soc. London, Trans. Transactions of the Linnean Society, London.
Linnean Soc. N. S. W., Proc. Proceedings of the Linnean Society of New South Wales.
Liverpool Geol. Soc., Proc. Proceedings of the Liverpool Geological Society.
Lotos, Prag. Lotos, Prag.
Louvain, Univ. Inst. geol., Mém. Mémoires de l'institut géologique de l'université de Louvain.
Lunds geol. fältk., Meddel. Meddelande fran Lunds geologiska fältklubb.
Lunds Univ. årssk. Lunds Universitets årsskrift.
Lyon, Univ., Ann. Annales de l'université de Lyon. I. Sciences, Médicine.

McGill Univ., Papers Dept. Geol. Papers from the Department of Geology McGill University.
Mähr. Landesmus. Brünn, Zeit. Zeitschrift des Mährischen Landesmuseums Brünn.
Manchester Phil. Soc., Mem. & Proc. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
Marseille, Fac. sci., Ann. Annales de la Faculté des sciences de Marseille.
Marseille, Mus. hist. nat., Ann. Annales del Musée d'histoire naturelle de Marseille.
Matér. carte géol. Suisse. Matériaux pour la Carte géologique de la Suisse.
Matér. géol. Caucase. Matériaux pour la géologie du Caucase, Tiflis.
Mater. Geol. Russ. Materialien zur Geologie Russlands.
Med. Grønland. Meddelelser om Grønland.
Med. indust. Finland. Meddelanden fran industristyrelsen i Finland.
Med.-naturw. Gesell. Jena, Denks. Denkschriften der medicinisch-naturwissenschaftlichen Gesellschaft zu Jena.
Mededeel. Rijksop. Delfstof. Mededeelingen van de Rijksopsporing van Delfstoffen.
Melbourne, Nat. Mus., Mem. Memoirs of the National Museum, Melbourne.
Md. Geol. Surv. Maryland Geological Survey.
Mexico. Dept. minas, bol. min. Boletin minero, organo del Departamento de minas, Mexico.
Mexico Inst. geol., An. Anales del Instituto geológico de Mexico.
Mexico Inst. geol., Bol. Boletín del Instituto geológico de Mexico.
Mich. Acad. Sci., Ann. Rept. Annual Report of the Michigan Academy of Science.
Mich. Acad. Sci., Bull. Bulletin of the Michigan Academy of Science.
Mich. Geol. Surv. Geological Survey of Michigan.
Min. & Eng. World. Mining and Engineering World.
Min. & Sci. Press. Mining and Scientific Press.
Min. Ind. Mineral Industry.
Min. Mag. Mineralogical Magazine.
Min. Sci. Mining Science.
Minn. Geol. Surv., Bull. Bulletin of the Minnesota Geological Survey.
Minn. Sch. Mines Exp. Sta., Bull. Bulletin of the University of Minnesota, Minnesota School of Mines Experiment Station.
Miss. Geol. Surv., Bull. Bulletin of the Mississippi State Geological Survey.
Mitth. Osterlande. Mittheilungen aus dem Osterlande, herausg. von der Naturforschenden Gesellschaft des Osterlandes.
Mitth. Pollichia. Mittheilungen der Pollichia, Dürkheim.
Mitth. staat. Bohr. Niederl. Mittheilungen der staatlichen Bohrverwaltung in den Niederlanden.
Mo. Bur. Geol. Missouri Bureau of Geology & Mines.
Mo. Geol. Surv. Missouri Geological Survey.
Mo. Hist. Rev. Missouri Historical Review.
Mo. Univ. Studies. University of Missouri Studies.
Montana Univ., Bull. University of Montana Bulletin.
Mus. cienc. nat. Madrid, Trab. Trabajos del Museo nacional de ciencias naturales Madrid, [Serie geológica].
Mus. géol. Pierre le Grand, Trav. Travaux du Musée géologique Pierre le Grand.
Mus. hist. nat. Belg., Mém. Mémoires du Musée royal d'histoire naturelle de Belgique.
Mus. hist. nat. Paris, Nouv. arch. nouvelles Archives du Museum d'histoire naturelle, Paris.
Mus. min. univ. Copenhague, Com. geol. Museum de minéralogie et de géologie de l'université de Copenhague. Communications géologiques.
Mus. nac. Buenos Aires, An. Anales del Museo nacional de Buenos Aires.
Mus. Paul., Rev. Revista do Museu Paulista.

N. C. Geol. Surv., Bull. Bulletin of the North Carolina Geological and Economic Survey.
N. J. f. Min. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
N. J. f. Min., B. B. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band.
N. J. Geol. Surv., Bull. Bulletin of the Geological Survey of New Jersey.
N. J. Geol. Surv., Final Rept. Final Report of the State Geologist of New Jersey.
N. S. Wales Geol. Surv., Mem. Pal. Memoirs of the Geological Survey of New South Wales, Paleontology.
N. S. Wales Geol. Surv., Min. Res. Mineral Resources of the Geological Survey of New South Wales.
N. S. Wales Geol. Surv., Rec. Records of the Geological Survey of New South Wales.

N. Y. Acad. Sci., Ann. Annals of the New York Academy of Sciences.
N. Y. Acad. Sci., Mem. Memoirs of the New York Academy of Sciences.
N. Y. Acad. Sci., Sci. Surv. P. R. New York Academy of Sciences, Scientific Survey of Porto Rico and the Virgin Islands.
N. Y. State Mus., Bull. Bulletin of the New York State Museum.
N. Y. State Mus., Mem. Memoirs of the New York State Museum.
N. Y. State Mus., Rept. State Geol. Report of the State Geologist.
N. Z. Geol. Surv., Ann. Rept. Annual Report of the Geological Survey of New Zealand.
N. Z. Geol. Surv., Bull. Bulletin of the Geological Survey of New Zealand.
N. Z. Geol. Surv., Pal. Bull. Palaeontological Bulletin of the Geological Survey of New Zealand.
N. Z. Inst., Trans. & Proc. Transactions and Proceedings of the New Zealand Institute.
N. Z. Journ. Sci. New Zealand Journal of Science and Technology.
Nat. Acad. Sci., Mem. Memoirs (or Biographical Memoirs) of the National Academy of Sciences, Washington.
Nat. Acad. Sci., Proc. Proceedings of the National Academy of Sciences, Washington.
Nat. Hist. Soc. Hertford. Transactions of the Natural History Society of Hertford.
Nat. Hist. Soc. New Brunswick, Bull. Bulletin of the Natural History Society of New Brunswick.
Natal & Zululand Geol. Surv., Rept. Reports of the Geological Survey of Natal and Zululand.
Naturalist. Naturalist, London.
Naturf. Gesell. Basel, Verh. Verhandlungen der naturforschenden Gesellschaft, Basel.
Naturf. Gesell. Freiburg i. B., Ber. Berichte der naturforschenden Gesellschaft, Freiburg (Baden).
Naturf. Gesell. Graubündens, Jahresb. Jahresbericht der naturforschenden Gesellschaft Graubündens.
Naturf. Gesell. Zurich, Vier. Vierteljahrsschrift der naturforschenden Gesellschaft in Zurich.
Naturh. Gesell. Colmar, Mitth. Mittheilungen der naturhistorischen Gesellschaft in Colmar.
Naturh. Gesell. Nürnberg, Abh. Abhandlungen der naturhistorischen Gesellschaft zu Nürnberg.
Naturh. Hofmus. Wien, Ann. Annalen des k. k. naturhistorischen Hofmuseums, Wien.
Naturh. Ver. preuss. Rheinl., Sitz. Sitzungsberichte herausgegeben von naturhistorischen Verein der preussischen Rheinlande und Westfalens.
Naturh. Ver. preuss. Rheinl., Verh. Verhandlungen des naturhistorischen Vereins der preussischen Rheinlande, Westfalens und des Regierungs-Bezirks Osnabrück.
Naturw. Ver. Magdeburg, Jahresb. u. Abh. Jahresberichte und Abhandlungen des naturwissenschaftlichen Vereins in Magdeburg.
Naturw. Ver. Schles.-Holstein, Schr. Schriften des naturwissenschaftlichen Vereins für Schleswig-Holstein.
Naturw. Ver. Steiermark, Mitth. Mittheilungen des naturwissenschaftlichen Vereins für Steiermark.
Nautilus. Nautilus.
Nebraska Bd. Agri., Ann. Rept. Annual Report of Nebraska State Board of Agriculture.
Nebraska Geol. Surv. Nebraska Geological Survey.
Niedersäch. geol. Ver., Jahresb. Jahresbericht des niedersächsischen geologischen Vereins.
Norges geol. Undersøk. Norges geologiska Undersøkelse.
Norsk. geol. Tidsskr. Norsk geologisk Tidsskrift.
North Stafford. Field Club, Trans. Transactions of the North Staffordshire Field Club.

Oberrhein. geol. Ver., Ber. u. Versamml. Bericht über die Versammlungen des oberrheinischen Vereins.
Ohio Acad. Sci., Proc. Proceedings of the Ohio State Academy of Science.
Ohio Geol. Surv., Bull. Bulletin of the Geological Survey of Ohio.
Ohio Nat. Ohio Naturalist.
Okla. Geol. Surv., Bull. Bulletin of the Oklahoma Geological Survey.
Ontario Bur. Mines, Rept. Report of the Bureau of Mines, Ontario.
Oregon Univ., Bull. Bulletin of the University of Oregon.
Ottawa Nat. Ottawa Naturalist.

Padua, Univ., Mem. inst. geol. Memorie dell'instituto geologico della R. universita di Padova.
Palæont. Abh. Palaeontologische Abhandlungen.
Palæont. ital. Palaeontographia italica.

Palaeont. Soc. Publ. Palaeontographical Society Publications.
Paläont. Zeit. Palaeontologische Zeitschrift.
Palaeontographica. Palaeontographica.
Pam. fizyog. Pamietnik fizyograficzny Warszawa.
Pan.-Am. Sci. Cong. Wash. D. C., Proc. Proceedings of Pan-American Scientific Congress, Washington, D. C.
Penna. Geol. Surv., Rept. Report of the Topographic and Geologic Survey of Pennsylvania.
Peru. Ing. minas, Bol. Boletin del cuerpo de ingenieros de minas del Peru.
Phys.-med. Soc. Erlangen, Sitz. Sitzungsberichte der physikalisch-medicinischen Societät zu Erlangen.
Phys.-ökon. Gesell. Konigsberg, Schr. Schriften der physikalisch-ökonomischen Gesellschaft, Königsberg in Pr.
Pont. Accad. rom. Lincei, Atti. Atti della Pontificia accademia romana dei nuovi Lincei.
Portugal. Serv. geol., Comm. Communicaçoes du Commissão do serviço geologico de Portugal.
Princeton Univ. Cont. Geol. Newfoundland. Princeton University Contributions to the Geology of Newfoundland.
Princeton Univ. Exp. Patagonia, Repts. Reports of the Princeton University Expeditions to Patagonia, 1896–1899.
Prussia. Geol. Landesanst., Abh. Abhandlungen der königlich preussischen geologischen Landesanstalt.
Prussia. Geol. Landesanst., Jahrb. Jahrbuch der königlich preussischen geologischen Landesanstalt.
Publ. cienc. nat. Barcelona. Publicacions de la junta de ciències naturales de Barcelona.

Quebec Dept. Coloniz. Mines Br. Province of Quebec, Canada, Department of Colonization, Mines and Fisheries, Mines Branch.
Queensland Geol. Surv., Publ. Queensland Geological Survey. Publications.

Res. Tenn. The Resources of Tennessee.
Res. wissen. Erf. Balatonsees. Resultate der wissenschaftlichen Erforschung des Balatonsees.
Rev. gén. bot. Revue général de botanique.
Riv. geog. ital. Rivista geografica italiana, Firenze.
Riv. ital. paleont. Rivista italiana paleontologia.
Riv. min. e crist. Rivista di mineralogia e cristallografia italiana.
Rochester Acad. Sci., Proc. Proceedings of the Rochester Academy of Science.
Roy. Dub. Soc., Econ. proc. Economic Proceedings of the Royal Dublin Society.
Roy. Dub. Soc., Sci. proc. Scientific Proceedings of the Royal Dublin Society.
Roy. Soc. Canada, Proc. & Trans. Proceedings and Transactions of the Royal Society of Canada.
Roy. Soc. Edinb., Proc. Proceedings of the Royal Society of Edinburgh.
Roy. Soc. Edinb., Trans. Transactions of the Royal Society of Edinburgh.
Roy. Soc. Lond., Phil. Trans. Philosophical Transactions of the Royal Society of London.
Roy. Soc. N. S. Wales, Journ. & Proc. Journal and Proceedings of the Royal Society of New South Wales.
Roy. Soc. S. Aust., Trans. & Proc. Transactions and Proceedings of the Royal Society of South Australia.
Roy. Soc. Vict., Proc. Proceedings of the Royal Society of Victoria.
Rumania. Inst. geol., An. Anuarul institutului geologic al Romaniei.
Russ. Cab. S. M., Sec. géol. Trav. Travaux de la section géologique du cabinet de sa majesté.
Russ. min. Gesell., Verh. Verhandlungen der russisch-kaiserlichen mineralogischen Gesellschaft zu St. Petersburg.
Russia. Com. géol., Bull. Bulletins du Comité géologique, Russie.
Russia. Com. géol., Mém. Mémoires du Comité géologique, Russie.

S. Afr. Mus., Ann. Annals of the South African Museum.
S. Afr. Phil. Soc., Trans. Transactions of the South African Philosophical Society.
S. Aust. Geol. Surv., Bull. Bulletin of the Geological Survey of South Australia.
S. Aust. Gov. Geol., Ann. Rept. Annual Report of South Australia Government Geologist.
S. Dak. Geol. Surv., Bull. Bulletin of the South Dakota Geological Survey.
S. Dak. Geol. Surv., Circ. Circular of the South Dakota Geological Survey.
S. Dak. Sch. Mines, Bull. South Dakota School of Mines, Bulletin, Department of Geology.

Sachs. Akad. Wissen. Leipzig, Abh. Abhandlungen der sächsischen Akademie der Wissenschaften. Mathematische-physikalische Klasse.

Sachs. Akad. Wissen. Leipzig, Ber. u. d. Verh. Berichte über die Verhandlungen der sächsischen Akademie der Wissenschaften zu Leipzig. Mathematische-physikalische Klasse.

St. Louis Acad. Sci., Trans. Transactions of the Academy of Science of St. Louis.

San Diego Soc. Nat. Hist., Trans. Transactions of the San Diego Society of Natural History.

Saxony. Geol. Karte, Erläut. Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen.

Sch. Min. Quart. School of Mines Quarterly.

Schw. naturf. Gesell., N. Denk. Neue Denkschriften der allgemeinen schweizerischen Gesellschaft für die gesammte Naturwissenschaften.

Schw. naturf. Gesell., Verh. Verhandlungen der schweizerischen naturforschenden Gesellschaft.

Schw. paläont. Gesell., Abh. Abhandlungen der Schweizerischen paläontologischen Gesellschaft. *See also* Soc. paläont. suisse, Mem.

Schwed. Südpolar Exp. 1901–1903, Wissenschaft. Ergeb. Wissenschaftliche Ergebnisse der Schwedischen Südpolar Expedition, 1901–1903.

Sci. Science.

Sci. et nat. Brux. Science et nature, Bruxelles.

Sci. Prog. Science Progress in the Twentieth Century.

Scotland Geol. Surv., Mem. Memoirs of the Geological Survey, Scotland.

Seis. Soc. Am., Bull. Bulletin of the Seismological Society of America.

Senckenb. naturf. Gesell., Abh. Abhandlungen herausgegeben von der Senckenbergischen naturforschenden Gesellschaft.

Senckenb. naturf. Gesell., Ber. Bericht der Senckenbergischen naturforschenden Gesellschaft.

Smith. Misc. Coll. Smithsonian Miscellaneous Collections.

Smith. Inst., Ann. Rept. Annual Report of the Smithsonian Institution.

Smith. Inst. Publ. Smithsonian Institution Publications.

Soc. anthro. Lyon, Bull. Bulletin de la Société d'anthropologie de Lyon.

Soc. anthro. Paris, Bull. Bulletin et mémoires de la Société d'anthropologie de Paris.

Soc. belge astron. Société belge d'astronomie de meteorologie et de physique du globe.

Soc. belge géol., Brux., Bull. Bulletin de la Société belge de géologie, de paléontologie et d'hydrologie. Brussels.

Soc. belge géol., Brux., Mém. Mémoires de la Société belge de géologie, de paléontologie et d'hydrologie. Brussels.

Soc. belge géol. Brux., Nouv. mém. Nouveaux mémoires de la Société belge de géologie, de paléontologie et d'hydrologie. Brussels.

Soc. cient. "Antonio Alzate," Mem. Memorias y revista de la Sociedad cientifica "Antonio Alzate."

Soc. franç. min., Bull. Bulletin de la Société française de mineralogie.

Soc. géol. Belg., Ann. Annales de la Société géologique de Belgique.

Soc. géol. Belg., Mém. Mémoires de la Société géologique de Belgique.

Soc. géol. France, Bull. Bulletin de la Société géologique de France.

Soc. géol. France, Mém. Mémoires de la Société géologique de France.

Soc. geol. ital., Boll. Bollettino della Società geologica italiana.

Soc. geol. Mex., Bol. Boletin de la Sociedad geologica Mexicana.

Soc. géol. Nord, Ann. Annales de la Société géologique du Nord.

Soc. géol. Normandie, Bull. Bulletin de la Société géologique de Normandie.

Soc. hist. nat. Chambéry, Bull. Bulletin de la Société d'histoire naturelle Chambéry.

Soc. ing. ital., Ann. Annali della Società degli ingegneri e architetti italiani, Roma.

Soc. lig. sci. nat., Genova, Boll. Bollettino della Società ligustica di scienze naturali e geografiche Genova.

Soc. linn. Lyon, Ann. Annales de la Société linnéenne de Lyon.

Soc. nac. min. Santiago, Bol. Boletin de la Sociedad nacional de mineria Santiago de Chile.

Soc. nat. Kiev, Mém. Mémoires de la Société des naturalistes de Kiev.

Soc. nat. mat. Modena, Atti. Atti della Società dei naturalisti e matematici, Modena.

Soc. nat. Moscou, Bull. Bulletin de la Société impériale des naturalistes de Moscou.

Soc. nat. Moscou, Nouv. mém. Noveaux mémoires de la Société impériale des naturalists de Moscou.

Soc. nat. Podolie, Mém. Mémoires de la Société des naturalistes et des amis de la nature en Podolie.

Soc. neuch. sci. nat., Bull. Bulletin de la Société neuchâteloise des sciences naturelles.

Soc. paléont. suisse, Mém. Mémoires de la Société paléontologique suisse.
Soc. phys. Genève, Mém. Mémoires de la Société de physique et d'histoire naturelle de Genève.
Soc. port. sci. nat., Mém. Mémoires publies par la Société portugaise des sciences naturelles.
Soc. sci. nat. Ouest, Bull. Bulletin de la Société des sciences naturelles de l'Ouest.
Soc. sci. nat. Saône-et-Loire, Bull. Bulletin de la Société des sciences naturelles de Saône-et-Loire.
Soc. sism. ital., Boll. Bollettino della Societa sismologica italiana.
Soc. statist. Isère, Bull. Bulletin de la Société de statistiques, des sciences naturelles et des arts industriels de l'Isère.
Soc. vaud. sci. nat., Bull. Bulletin de la Société vaudoise des sciences naturelles.
Spain. Com. geol., Bol. Boletin de la Comisión del mapa geológico de España.
Spain. Inst. geol., Bol. Boletin del Instituto geologico de España.
Spelunca. Spelunca, Bulletin et Mémoires de la Société de spéléologie.
Sven. Vetenskap. Handl., Arsbok. k. Svenska Vetenskapsakademien handlingar, Årsbok.
Sweden. Sver. geol. Undersök. Sveriges geologiska undersökning.

T. M. P. M. Tschermak's mineralogische und petrographische Mittheilungen.
Tasmania Geol. Surv., Bull. Tasmania Geological Survey Bulletin.
Tasmania Geol. Surv., Rec. Tasmania Geological Survey Records.
Tenn. Acad. Sci., Trans. Transactions of the Tennessee Academy of Science.
Tenn. Geol. Surv., Bull. Bulletin of the Tennessee Geological Survey.
Texas Acad. Sci., Trans. Transactions of the Texas Academy of Science.
Texas Univ., Bull. Texas University, Bulletin.
Tokyo Imp. Univ. Coll. Sci., Journ. Journal of the College of Science, Imperial University of Tokyo, Japan.
Toronto Univ., Studies. University of Toronto Studies, Geological Series.

U. S. Bur. Mines, Bull. Bulletin of the United States Bureau of Mines.
U. S. Bur. Mines, Repts. Invest. Reports of Investigations of United States Bureau of Mines.
U. S. Bur. Mines, Tech. Papers. Technical Papers of the United States Bureau of Mines.
U. S. Geol. Surv., Bull. Bulletin of the United States Geological Survey.
U. S. Geol. Surv., Geol. Atlas. Geologic Atlases of the United States Geological Survey.
U. S. Geol. Surv., Min. Res. United States Geological Survey. Mineral Resources of the United States.
U. S. Geol. Surv., Mon. Monographs of the United States Geological Survey.
U. S. Geol. Surv., Prof. Paper. Professional Papers of the United States Geological Survey.
U. S. Geol. Surv., Water-Supply Paper. Water-Supply Papers of the United States Geological Survey.
U. S. Nat. Mus., Bull. Bulletin of the United States National Museum.
U. S. Nat. Mus., Proc. Proceedings of the United States National Museum.
Union S. Afr. Geol. Surv., Mem. Union of South Africa Geological Survey. Memoirs.
Upsala Univ., Bull. Geol. Inst. Bulletin of the Geological Institution of the University of Upsala.

Va. Geol. Surv., Bull. Bulletin of the Virginia Geological Survey.
Ver. Natur. Mecklenburg, Arch. Archiv des Vereins der Freunde der Naturgeschichte in Mecklenburg.
Ver. f. Erdk. Darmstadt, Notizb. Notizblatt des Vereins für Erdkunde zu Darmstadt.
Ver. Naturk. Württ., Jahresh. Jahreshefte des Verein für vaterländische Naturkunde in Württemberg.
Vermont State Geol., Rept. Report of the State Geologist on the Mineral Industries and Geology of Vermont.
Vict. Geol. Surv., Bull. Bulletin of the Geological Survey of Victoria.
Vict. Geol. Surv., Rec. Records of the Geological Survey of Victoria.
Vict. Inst. London, Journ. Journal of the Transactions of the Victoria Institute, London.

W. Austral. Geol. Surv., Bull. Bulletin of the Western Australia Geological Survey.
Wagner Inst. Sci., Trans. Transactions of the Wagner Free Institute of Science, Phila.
Wash. Acad. Sci., Proc. Proceedings and Journal of the Washington Academy of Science.
Wash. Geol. Surv., Ann. Rept. Annual Report of the Washington Geological Survey.
Wash. Geol. Surv., Bull. Bulletin of the Washington Geological Survey.

Wis. Geol. Surv., Bull. Bulletin of the Wisconsin Geological and Natural History Survey.
Wis. Nat. Hist. Soc., Bull. Bulletin of the Wisconsin Natural History Society.
Wyo. State Geol., Bul. Wyoming, Geologist's Office, Bulletin.

Yorks. Geol. Soc., Proc. Proceedings of the Yorkshire Geological Society.
Yorks. Nat. Union, Leeds, Trans. Transactions of the Yorkshire Naturalists' Union, Leeds.

Zeit. f. Gletscherk. Zeitschrift für Gletscherkunde.
Zeit. f. Kryst. Zeitschrift für Krystallographie und Mineralogie.
Zeit. f. prak. Geol. Zeitschrift für praktische Geologie.
Zeit. f. Vulkan. Zeitschrift für Vulkanologie.
Zool.-bot. Gesell. Wien, Abh. Abhandlungen der k. k. zool.-bot. Gesellschaft in Wien.
Zool. Rec. Zoological Record.

PART I

GENERAL BIBLIOGRAPHIES

A. Current[1] Bibliographies and Abstract Journals.

1 **American geological literature,** monthly authors' catalogue arranged alphabetically. Am. Geol., 29–36, 1902–1905. 1902, vols. 29–30; 1903, vols. 31–32; 1904, vols. 33–34; 1905, vols. 35–36; (1902–05. Regional.)

2 **Annales des mines.** Bibliographie . . . 1896–1914. *Its* Mém. 9 sér. 9–20, 1896–1901; 10 sér. 1–20, 1902–11; 11 sér. 1–5, 1912–14;—(1896–1914. General.)

3 **Annuaire géologique** et minéralogique de la Russie. Vol. 1— Varsovie, 1896– ? ; (1896–1913. Regional.) Each volume contains a bibliography for the year indexed by subject.

4 **Bibliographia geologica.** Répertoire des travaux concernant les sciences géologiques dressé d'après la classification décimale. . . . . Bruxelles, 1897– ? . (1896–1904. General.) Editors: 1897–, M. Mourlon, with the collaboration of G. Simoens. In two series: A. Covering works published before 1896. B. Works published 1896–1904.

5 ***Bibliographie der deutschen naturwissenschaftlichen Litteratur.** Herausgegeben im Auftrage des Reichsantes des Innern von deutschen Bureau der international Bibliographie in Berlin. Jena, I Jahrg. 1901.

6 **Bibliographie geologique** du Portugal et de ses colonies 1893– . [Beginning with 1913– by P. Choffat and E. Fleury. 1893–1895 bear titles of Bibliographie only.] Portugal. Serv. geol., Comm. 3– , 1895– . 1893–97, vol. 3, 104–108, 294–299 (134 entries); 1894–1900, vol. 4, 228–236 (112 entries); 1898–1902, vol. 5, 254–277 (175 entries); 1902–05, vol. 6, 197–210, 213, 365–376 (137 entries); 1906–07, vol. 7, 187–221 (86 entries); 1908–09, vol. 8, 181–216 (103 entries); 1910–12, vol. 9, 248–288 (154 entries); 1913, vol. 10, 234–263 (86 entries); 1914, vol. 11, 145–198 (120 entries). (1107 entries. 1893–1914. Regional.)

7 **Bibliography of North American** geology for 1732– with subject index . . . Washington, 1896– . U. S. Geol. Surv., Bull. 127– . 1732–1891, Bull. 127, authors and subjects combined; 1892–1900, Bulls. 188, 189 (6548 entries); 1901–1905, Bull. 301 (ca 10,946 entries); 1906–07, Bull. 372 (2672 entries); 1908, Bull. 409 (1215 entries); 1909, Bull. 444 (1305 entries); 1910, Bull. 495 (1410 entries); 1911 Bull. 524 (1266 entries); 1912, Bull. 545 (1275 entries); 1913, Bull. 584 (1357 entries); 1914, Bull. 617 (1357 entries); 1915, Bull. 645 (1227 entries); 1916, Bull. 665 (1281 entries); 1917, Bull. 684 (1194 entries); 1918, Bull. 698 (1099 entries); 1919, (1732– . Regional.) 1732–1891 by N. H. Darton. 1892–1895 by F. B. Weeks, 1906–07 by F. B. Weeks and J. N. Nickles. 1908– by J. N. Nickles.

8 **Bibliography of petroleum** and allied substances; by E. H. Burroughs. U. S. Bur. Mines, Bull. 149– . 1915, Bull. 149 (1455 entries); 1916, Bull. 165 (1357 entries); 1917, Bull. 180 (1489 entries); 1918, Bull. 189 (1725 entries); 1919–20, in press. (6026 entries. 1915– . General.)
See 16.

9 **Förteckning öfver svensk** geologisk, paleontologisk, petrografisk och mineralogisk litteratur . . . av F.E. Åhlander. Geol. Fören. Stockh. Förh., 23, 1901– . 1899–1900, vol. 23, 185–198 (231 entries); 1901–03, vol. 25, 432–448 (293 entries); 1904–06, vol. 29, 49–67 (271 entries); 1907–17, vol. 41, 539–606 (1036 entries); 1918–19, vol. 42, 453–464 (193 entries); (2024 entries. 1899–1919. Regional.)

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[1] The term "current" applies to the period of the bibliography, not to the date of publication. Many of the entries listed have ceased publication.

*Not seen.

10 **Geological society, London.** Geological literature added to the Geological society's library during the half-year ended December, 1894- [No. 1]- (1895- . General.)

11 **Geologisches Zentralblatt,** 1, 1901— . (General; covers literature of all countries by reviews and indexed.)

12 **Index bibliographique** . . . par N. I. Krištafovič. Ann. géol. et min. Russ., 7, 1895, 1901, vol. 7–II, 1–47, (2807 entries); 1902, vol. 8–II, 1–56, (2237 entries); 1903, vol. 9–II, 1–52, (2059 entries); 1904, vol. 10–II, 1–54, (2366 entries); 1905, vol. 11- , 1–82, (3358 entries includes Suppl. 1896–06); 1906, *1907, *1908, *1909, *1910, 1911, vol. 14- , 1–76, (1909 entries); *1912, vol. 15- , 1–90. (Regional.)

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